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Working Paper

MANPRINT ANALYSIS OF THE DIVAD SYSTEM:
VOLUME II. LESSONS RELEARNED

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FOREWORD

This report is the second of two volumes presenting a MAN-PRINT analysis of the Division Air Defense (DIVAD) Gun System, also known as Sgt York. The first volume is a consolidation and analysis of the human factors data obtained from the Sgt York Follow-On Evaluation I tests. The second volume is a discussion of the lessons learned or, better, relearned from that experience.

From 2 April 1985 to 15 June 1985, Follow-On Evaluation tests were conducted to support an assessment of the Division Air Defense (DIVAD) Gun System, the Sgt York. The Force-on-Force phase was conducted at the Combat Development Experimentation Center (CDEC) at Fort Hunter-Liggett, CA, and the Live Fire phase was conducted at White Sands Missile Range in New Mexico.

Essex Corporation was under contract (MDA903-85-C-0229) to the U.S. Army Research Institute for the Behavioral and Social Sciences to carry out human factors, training, and safety analyses of the Sgt York. Mr. George Gividen, Chief of the ARI Field Unit at Fort Hood and ARI coordinator for human factors on the Sgt York FOE I test, was the Contracting Office Technical Representative (COTR) for that contract. A seven-man Essex human factors team was on-site as the Force-on-Force and Live Fire phases of the Sgt York FOE I tests were conducted. The team members were Mr. Richard H. Hiss, Mr. John R. Rice, Dr. Spencer C. Thomason, Mr. C. Henry Debow, Mr. Charles R. Sawyer, Mr. Philip Durham, and Mr. John C. Cotton. A preliminary account of the human factors, safety, and training results of FOE I was supplied for incorporation in the Operational Test and Evaluation Agency (OTEA) report on FOE I. Those results also provided a foundation for this two-volume work. Actual preparation of these two volumes was covered under Contract MDA903-83-C-0033 as one of the Task 3 Methodology studies. Dr. Charles O. Nystrom is the COTR on that contract.

Both of the present volumes owe an obvious debt to those human factors specialists who were in the field during the Sgt York FOE I tests. If they had not recorded and preserved what happened there, this report could not have been written. A specific indebtedness to Mr. Richard H. Hiss is acknowledged. By recounting events and details beyond what were recorded, he provided much greater insight into the meaning of the data. Although the words and conclusions of this report are the author's, they owe much to the discussions and data reviews held with Mr. Douglass R. Nicklas and Dr. Bettina A. Babbitt. Finally, two special contributions to this report are particularly appreciated. Dr. Frederick A. Muckler methodically reviewed and willingly discussed successive drafts of this report. Mrs. Joan Funk, with skill, judgment, and patience, deciphered the original manuscript, typed frequent revisions, and produced the final report.

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I. EXECUTIVE SUMMARY

This report is intended to examine lessons that were learned from the human factors aspects of the Sgt York Follow-On-Evaluation (FOE I) tests. A separate report (Babbitt, 1987) documents those tests, so details of system description and performance, test planning and execution, and data collection and analysis are not repeated in this report. The present focus is on (1) applying the experience of Sgt York FOE I to the larger issue of integrating good human factors design into the entire process of weapon system acquisition; (2) using the Sgt York FOE I observations to suggest improvements in human factors operational test and evaluation; (3) putting these observations into the context of the current Army-wide MANPRINT initiative; and (4) relating present findings to the results of earlier reverse engineering and design criteria studies of other major Army weapon system acquisitions (Stinger, Multiple-Launch Rocket System (MLRS), Fire Support Team Vehicle (FIST-V), and the Fault Detection and Isolation Subsystems of the M1 Tank).

The observations called "lessons" may be startling from a MANPRINT standpoint, but they are not really new. There are remarkable parallels for them in the development of earlier systems. Some may see them as old lessons too familiar to warrant recounting; others may find new insights or perspectives. However they are seen, they seem to need to be re-learned with each new system, so this volume is called lessons relearned to highlight the sense of (unfortunately) revisiting old territory.

To provide a context for the later discussions, there are brief descriptions of Forward Area Air Defense (FAAD), of the intended role of the Division Air Defense (DIVAD) Gun in the FAAD mission, of the acquisition history of DIVAD, and of the resulting DIVAD gun system and its operation. The third section reviews the human factors requirements that were imposed on the Sgt York system and the tests conducted on that system. Encompassed within the broader human factors domain are issues of training, safety, manpower, and personnel, as well as human engineering concerns associated with displays, controls, work-space, and the like. Not all these issues were addressed in the requirements documents, but specifications associated with any of these human factors considerations will be noted.

In the fourth section, human factors issues to which FOE I results are relevant are related to the current MANPRINT initiative. The final section considers what lessons can be learned from the DIVAD program, from earlier reverse engineering studies, and from other human factors operational tests that are applicable to future FAADS developments. That is, the final section addresses issues of continuing relevance to the

system acquisition process and to the successful integration into that process of the concerns which underlie the MANPRINT initiative.

This report is not meant to assign blame or to suggest guilt; rather it is intended to spotlight problems that may be avoidable in the development of future systems. Lessons can be learned by narrowly avoiding pitfalls as well as by falling into them. It should not be inferred from the discussion of any specific problem that the Sgt York project was a prime example or the worst case of that problem.

As Dr. Edgar M. Johnson (1986) has observed, "people problems are readily found in weapon systems." The Sgt York system was no exception. The Army scarcely needs one more report telling it what too many already know: It is very difficult to integrate good human factors engineering into the weapon acquisition process. It is not just a question of setting standards. Implementing them once they exist is at least as difficult. Past studies indicate that well over half of all HFE problems which are identified during operational tests could be avoided by following existing design criteria.

Adequate design criteria need to be available; once available, they need to be used. Ensuring and facilitating the use of design criteria appears the most urgent need. Clearly having the pertinent criteria available in a MIL-STD or MIL-HDBK is not enough. Somehow, the criteria that exist must become meaningful and familiar to weapon system design teams, if not to everyone on such a team, at least to someone, and failure to meet human factors criteria must be acknowledged for the serious problem it is. Making adequate human factors criteria available is only the first step in a progression that must include applying them.

A concerted effort was made to consider the FOE I test results without regard to the political context in which they were conducted, but one conclusion is inescapable: the urgency, the pressure, and the highly charged atmosphere which surrounded FOE I played a major part in the outcome of the tests. Preparations were rushed and incomplete; training was abbreviated; data collection and analysis were hurried, incomplete, and ad hoc. Too much and too little was done too quickly. Sgt York crewmembers were asked to operate a new, complex weapon system with too little training and too much stress. Test scenarios did not reflect adequately the problems suggested by earlier tests or the strengths built into the weapon system, partially if not primarily because of lack of familiarity with either one.

The questions that remained unanswered were substantial. For example, Sgt York offers some evidence that category IV soldiers (or at least this subset of them) can be trained to

operate a system as complex as the Sgt York. For future systems, this implies that category IV soldiers can be effective in systems operations. To presume that category IV soldiers are not appropriate for new sophisticated weapon systems is premature and may unnecessarily limit the manpower pool.

It is important that the shortcomings of the Sgt York FOE I tests not be attributed to lack of effort, talent, or motivation on the part of the participants. The problems faced were enormous; closer examination served to increase the estimate of their number and complexity. The efforts of those who took part were herculean; the variety of perspectives which somehow had to be merged was vast. Probably no test is ever conducted with the time for preparation, execution, and documentation that one would wish, or without problems arising, but Sgt York, whatever its merits or deficits, faced pressures that were overwhelming and obscuring.

Some of the lessons learned as a result of Sgt York are discussed in the final chapter. Several of them relate to the decision to build the Sgt York around the problem-laden M48 chassis, which meant the system started with a human factors engineering deficit. One of the lessons of Sgt York is that design problems such as those posed by that chassis can have a negative impact on crew performance and thereby on system performance that no amount of training and no current personnel selection criteria can offset completely. If crew compartments are to be small, perhaps selection criteria should be expanded to include physical size of the operators.

Another lesson concerns the impact of time pressures. If necessary support items are not available in time for them to be part of pre-test training, and if there is not enough pre-test time for operators to learn the system thoroughly, the test will not provide a valid picture of system capability. Test results will be confounded by factors that would later be resolved. System assessment is flawed to an extent that cannot be calculated. Pressure to hurry system assessment can be counterproductive; rather than speeding the process, it tends to invalidate the result.

Both Sgt York and earlier design criteria studies of a variety of weapon systems demonstrate that there are more and better human factors design criteria available than are used in designing the weapon systems that human beings must operate and maintain. Ways need to be found to incorporate hard-won knowledge about human factors requirements into new design efforts. Time and attention need to be allocated to that effort. Whatever inhibits the ability to identify past lessons and to apply them to present problems interferes with good design.

II. FAAD AND DIVAD

FORWARD AREA AIR DEFENSE

Forward Area Air Defense (FAAD) has evolved from the concept of Short Range Air Defense (SHORAD). SHORAD was to provide low altitude, short range air defense protection to Army components, primarily to armor and infantry units. The related expanded FAAD mission is to defend ground combat forces, combat support forces, or any other related critical assets against attack or surveillance by airborne hostile forces. Thus, it will be FAAD units that are responsible for providing air defense for maneuver elements in any future air-land battlefield.

The FAAD mission is an essential part of the overall air defense mission. A key aspect of the FAAD concept is battlefield integration. The FAAD mission is integrated into the U.S. Army Air Defense Artillery (ADA) mission, and FAAD operations are similarly to be integrated into ADA operations. Air Defense Artillery supports freedom of action for ground commanders so that they can maneuver without interference (or with minimized interference) from enemy air attack. That is, the ADA mission is to nullify or reduce the effectiveness of attack or surveillance by hostile aircraft or missiles after they are airborne. Thus, FAAD directly supports the primary Army function of conducting prompt and sustained land warfare operations.

DIVAD: ITS ROLE

Division Air Defense is one component of Forward Area Air Defense. The Division Air Defense (or DIVAD) gun system, also known as the Sgt York (U.S. Army M247 Gun System) was developed as a key element of Division Air Defense. The Sgt York gun system was intended to provide all-weather, close range air defense for forward area mobile tactical units against hostile fixed-wing aircraft, helicopters, and lightly armored ground vehicles. According to the Sgt York Operational and Organization (O&O) Plan, Sgt York's mission was to operate as an integral part of combined arms teams and to be mobile and survivable enough to support front line armor, mechanized infantry, and armored cavalry units. Sgt York was meant to provide low altitude air defense against attacks by high performance fixed-wing aircraft and helicopters. Its primary Soviet targets were described as armed, anti-armor helicopters (e.g., in NATO terminology, HIND/HAVOC) and fixed-wing, close air support aircraft (e.g., FITTER, FROGFOOT). DIVAD was to replace the self-propelled Vulcan Air Defense System as the main air defense gun system for Army heavy divisions.

In addition to providing close range air defense for maneuvering units, the Sgt York gun had an inherent self-defense capability and could provide ground fire against lightly armored vehicles as well as against hostile ground personnel. Since this DIVAD gun system was intended for use in far forward positions, it was also to engage threat aircraft at a vulnerable period for them, i.e., when they were en route to ordnance launch positions.

DIVAD: ITS ACQUISITION

In August 1976, an Army document was issued that formalized the Required Operational Capability (ROC) for a "New Air Defense Gun." As stated in that document, "This program's goal is to provide a gun as quickly as possible utilizing either an off-the-shelf available system or proceeding with a development program that makes maximum use of existing technology." In discussing the time frame of system acquisition, the ROC said that an Initial Operational Capability (IOC) was "desired" by CY 1980, and that "The first battalion IOC is required by 1983."

Some highlights of the Sgt York acquisition are included in Table 1 and will not be detailed further here. The Sgt York Follow-On Evaluation test, which is the principal source of data and focus for this report, began on 2 April 1985, and continued through 15 June 1985.

DIVAD: ITS DESCRIPTION

The DIVAD gun was an integrated, independent weapon system equipped with two 40-mm automatic guns mounted on a self-propelled, fully armored, tracked vehicle. Figure 1 shows a drawing of the Sgt York and contains a system description as prepared by Ford Aerospace and Communications Corporation (FACC), the prime contractor for the weapon system.

The hardware may be grouped into four major subsystems: (1) armament, (2) radar-directed fire control, (3) power and actuation, and (4) a Government-furnished, modified M48A5 tank chassis. In Figure 1, elements of the fire control system are described separately. The search and track radar is differentiated from the fire control and display components. In addition, the squad leader's periscope and the gunsight are called out individually. In the figure, the armament subsystem is broken down into three elements, and the turret and the chassis are described briefly.

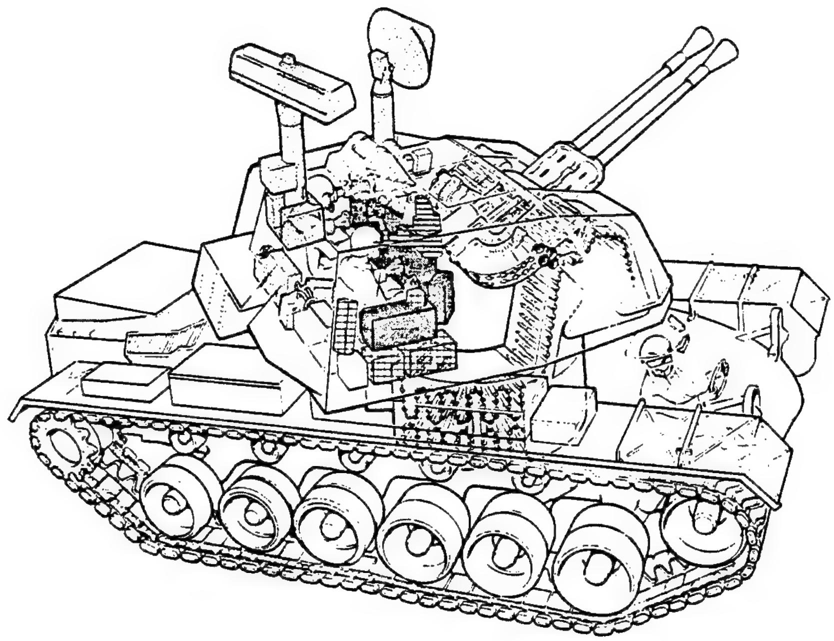
Each of the four major subsystems is described below to provide a context for later discussion.

<u>Armament Subsystem</u>. The Sgt York had two 40-mm L/70 Bofors cannons, usable singly or in pairs, and designed for automatic, semiautomatic, or limited manual operations. The

Table 1. SGT YORK ADG ACQUISITION HISTORY

Design Periods (number of months)	YEAR	MONTH	EVENT
	1976	AUG	Required Operational Capability issued: Initial Operation Capability by CY 1980; first battalion IOC by 1983
	1977	FEB	Defense Systems Acquisition Review Council I: development plan for new air defense gun
		APR	SecDef approved a contingent development program; RFP issued
29	1978	JAN	DSARC II: two prototype development contractors, FACC & GD
	1979		
	1980	MAR-MAY	Contractors' testing
		MAY-JUN	Contractors' demonstrations
		JUN-NOV	DT/OT begins
7	1981	MAY	FACC selected to produce DIVAD
		NOV-	Check test of single fire unit: DT II A
18	1982	JAN	
	1983	JUN-AUG	Engineering Production Unit Test (EPUT) at Ft. Bliss: DT II B
	1984	JUL-AUG	Sgt York Limited Test at Ft. Bliss
		NOV-	Initial Production Test (IPT) North McGregor Range; Ft. Bliss; Ft. Huachuca; Aberdeen Proving Ground
	1985	MAY	
		APR-JUN	Follow-On Evaluation (FOE) I Force-on-Force Phase: Combat Development Experimentation Center (CDEC), Ft. Hunter-Liggett, CA Live Fire Phase: White Sands Missile Range, NM

U.S. ARMY M247 GUN SYSTEM



SYSTEM DESCRIPTION

ARMAMENT

GUNS
- Twin L/70 40mm Automatic guns
- Rate of Fire: 300 rounds per minute per gun
- NATO standard and interoperable with other L/70 guns

FEED SYSTEM
- Linkless feed
- Upper and lower magazine for each gun
- Upper magazine capacity: 82 rounds each
- Lower magazine capacity: 169 rounds each
- Total feed system capacity: 502 rounds

COMBAT AMMUNITION
- Proximity-fuzed projectile with 640 tungsten pellets
- High explosive projectile with delay action
- Interoperable with any L/70 gun

SEARCH/TRACK RADAR
- Pulse doppler
- Three beams provide full elevation coverage
- Fully automatic
- Integrated identification friend or foe (IFF)
- ECCM provisions
- Automatic self-calibration

FIRE CONTROL
- Automatic threat prioritization
- Automatically selects ammunition type and burst schedule
- Automatic lead angle computation
- Automatic meteorology inputs
- Manual overrides for all computer controlled functions
- Direct/Indirect fire capability against ground targets

COMBAT DISPLAY
- Targets (friend or foe) displayed with prioritization symbology for threat targets
- Primary target line, search sector limits and range rings displayed
- Hull, guns, gunsight, and periscope direction displayed
- Ammunition status, acquisition mode, and system status displayed

OPTICS

GUNSIGHT
- Stabilized day/night sight with integrated laser rangefinder
- 5^{o} day/3^{o} night field of view
- 30^{o} azimuth gimbal with -5 to $+85^{o}$ elevation
- 12 X day/16 X night

SQUAD LEADER'S PERISCOPE
- Independent of gunsight
- 360^{o} under armor stabilized day/night search
- 20^{o} day/12^{o} night field of view
- 3 X day/4 X night

TURRET
- Rolled homogeneous armor steel
- Environmentally controlled

CHASSIS
- Modified M48A5 tank chassis
- Track, engine and transmission common with M60 series tank

Figure 1. The Sgt York Fire Unit.

combined rate of fire was 600 rounds/minute. The guns were recoil operated. The cases were ejected base first through chutes that were fixed relative to the turret, with exit ports just outboard of the guns. Cases were ejected clear of the vehicle, away from the centerline of the gun. Both guns and their feed systems were independent; disabling one gun did not render the other unusable.

The weapons were mounted on a single non-recoiling cradle which provided a base for the elevating mass and a platform for fire, whether the vehicle was stationary or in motion. The weapon system was designed to operate over rough as well as smooth terrain.

Fire Control Subsystem. Included in this subsystem were a fire control computer (FCC), a search and track (S/T) radar, an identification friend or foe (IFF) system, an optical subsystem, an attitude reference unit (ARU), communication equipment, and fire control subsystem controls and displays. The optical subsystem included a tracking telescope, a panoramic periscope, and a laser range finder.

Power and Actuation Subsystem. Except for the Primary Power Unit, this subsystem was contained within the turret. The turret structure was made of rolled, homogeneous armor to protect the squad leader, the gunner, and the internally mounted equipment. The track antenna and the search antenna were mounted external to the turret, but could be stowed in a protected position. The gunsight and the squad leader's periscope were encased in armor housings for protection. The commander's hatch and the gunner's hatch provided access to the turret from the outside. In addition, there were two outside exits from the driver's compartment that were accessible to the other crewmembers when the turret was pointed aft. The turret was capable of traversing 360 degrees, with a maximum rate of 90 degrees per second; that is, it could completely reverse its heading in only two seconds.

Mobility Subsystem. The Sgt York was mounted on an M48A5 tank chassis with a modified hull. The aft grill had been extended 17.1 inches in order to accommodate the primary power unit (PPU) and the electrical and hydraulic power generation equipment. Otherwise, no changes were made in the single piece, cast armor hull. The PPU was mounted in a separate compartment aft of the M48A5 tank engine. The tank's main engine provided back-up power for the turret when the vehicle was stationary. The suspension of the M48A5 chassis was modified because of the weight of the Sgt York systems.

DIVAD: ITS OPERATION

The Sgt York gun system was designed to be operated by a three-man crew. Two of them, a squad leader and a gunner, were located in a crew compartment in the rear of the turret; and

the third, a driver, was in the front portion of the hull. The two combat crewmembers sat side-by-side, the squad leader on the right and the gunner on the left. The fire control display was located between them with the controls accessible to either one. The turret crewmen were responsible for target acquisition, identification, and engagement; the driver was responsible for maneuvering the vehicle. The turret crewmen, as well as the fire control equipment, the armament, and the ammunition feed system, moved with the turret as it turned. Since the driver did not move with the turret, his position with respect to the other crewmen might change from moment to moment.

Target Engagement Sequence

Although integrating the operation of a given Sgt York fire unit (FU) into the overall operation of a FAAD unit was conceived to be a three-man job, carrying out a target engagement sequence was intended to involve two men, the squad leader and the gunner, operating as hunter and killer, respectively. However, system instrumentation was designed so that one-man operation was possible if the situation demanded it. The squad leader and the gunner sat side-by-side and had equal access to system control and display elements. It was expected that the one-man operation could handle fewer targets and would be less effective over time than two-man operations.

Sgt York was designed to search for, detect, identify, track, and range hostile targets automatically, manually, or in a combination mode. A radar-based system was provided to detect a target, determine its range, and track it automatically. The final step in the engagement sequence, firing on a target, was not automatic; it required human judgment and intervention.

In addition to the radar search and fire control capability, there was a laser range finder (similar to that provided for Vulcan). With the laser range finder, an entirely optical engagement could be carried out without radar, or the laser capability could be used to supplement the radar system. There were gunsight and periscope telescopes for target search and for target engagement monitoring. As a target was being tracked, the radar control computer would provide a signal or firing cue to indicate that the target was sufficiently "visible" to the tracking system to make successful target engagement likely. It was then up to a crewmember, the squad leader or the gunner, to make the actual decision to fire.

The fully coherent pulse doppler radar provided a search-while-track capability. Thus, new targets could be picked up by the search radar while a target that had already been selected continued to be followed by the tracking radar. The radar subsystem was designed to be resistant to electronic countermeasures and to false return information. The radar search function operated in conjunction with a fully integrated

IFF system. The IFF system did not operate unless the radar control computer was operating.

Modes of Operation

Automatic Mode of Operation. In the fully automatic mode, the Sgt York gun system would initiate an engagement sequence and carry it through to the point at which a steady fire-enable cue was displayed. During the automatic functioning of the radar subsystem, the crewmen would monitor the target engagement using the periscope and gunsight telescopes. The fire control computer (FCC) would automatically direct the fire control system to the target. The speed of turret slew when combined with the unpredictability of target appearance made it imperative that the crew be buttoned up when operating in the automatic mode, and careful about the position of their body parts even then.

If more than one engageable target was present, the FCC would direct the system and the operator to the target that posed the greatest threat (i.e., had the highest priority). As the target moved into the recommended firing range and the engagement sequence drew to a close, the small target symbol shown on the combat display would change to a large symbol, and the radar alert lamp would change from a blinking to a steady light. Both the optical system (periscope and gunsight) and the display would present indications of whether the firing solution was based on radar data, laser data, or both. At this point, it would be up to the crewmen to make the firing decision. The automatic system could continue to track the target, but it could not fire on a target. Either the gunner or the squad leader, after verifying that the target was hostile, would have to complete the engagement by firing the weapons.

Manual Mode of Operation. In the manual mode, the squad leader would detect and locate a target visually, either using his periscope or operating with his head out of the turret; he would designate the target and use the laser system to establish its range, and would pass it off to the gunner who would complete the engagement sequence. If the gunner was not occupied with an earlier target engagement, the new target could be passed off to him at any time for him to track and engage while the squad leader searched for other targets. In the manual mode, all target identification had to be performed visually by one of the crewmembers.

Combination Mode of Operation. The combination mode was a semiautomatic or mixed mode. In this mode, the radar system was used to detect targets, but the crewmembers customarily maintained control over the turret by tracking each target manually. So long as they maintained this control, they avoided the sudden and hazardous slew of the turret that would result if it turned automatically to track a newly detected target.

This combination mode was considered the primary operational mode for the Sgt York.

Hazards of Target Slew

In reacting to hostile targets, the quicker the accurate response of the defense system the better; in that sense, the Sgt York slew rate of 90 degrees per second was a positive feature. However, for the crew which shared the turret and for the driver who sat directly below that turret, the very responsiveness of the Sgt York constituted a problem. There was a warning contained in the Sgt York operating manual (TM9-2350-309-10-2, p. 2-447):

WARNING

> In radar auto mode turret slews automatically with little or no warning if engageable target appears and palm switch is enabled. Sudden slew can cause injury. Gunner and squad leader must wear properly adjusted seat harnesses and CVC [combat vehicle crewman] helmets [to reduce the possibility of] injury.

There was a similar warning in the instruction on the use of the pointer (p. 2-449):

WARNING

> Setting RDR switch to POINTER causes immediate slew to pointer-designated target at any rate (unless IFF identifies it as a friend). Sudden slew can cause injury. Wear properly adjusted seat restraints and CVC helmet. Be prepared for slew.

Had the system operators been remote from the turret, its response rate would not have been a hazard; in the turret, it was.

External Communications

In addition to operating as the combat engagement monitor and controller, the squad leader had another responsibility during Sgt York operations. Regardless of the operating mode, to integrate a Sgt York fire unit into division operations, the squad leader would have had to communicate with the external command and control structure, as well as with the other members of the DIVAD crew. Each DIVAD fire unit was intended to operate as an integral part of a four-squad platoon, and each platoon was to be part of a Sgt York/Stinger battery that included a MANPADS (man-portable air defense system) platoon as well as three gun platoons. Obviously, coordination and the communication attendant to it would be important to a fire unit's operation.

III. HUMAN FACTORS REQUIREMENTS: SPECIFICATIONS AND TESTS

HUMAN FACTORS REQUIREMENTS IMPOSED ON DIVAD

At various stages in the system development process, certain human factors requirements were imposed on the Sgt York Air Defense Gun. There were three sources for these human factors requirements: statements contained in the Required Operational Characteristics (ROC) document, technical requirements included in the Request for Proposal (RFP), and the contract specifications. These requirements centered on three separate issues: (1) crew size, (2) crew safety, and (3) human engineering concerns.

Crew Size

The ROC stated that "It is envisioned that there will be a crew of three or four, including the driver." The ROC also directed that "It is desirable that the turret be designed for two crewmembers (the commander and gunner) if cost effective" (Paragraph 5(h)). The RFP agreed that the "crew size shall not be less than 3." The contract specification included some additional details:

> "3.1 The launch system shall be manned by a 3-man crew consisting of a squad leader, gunner, and driver. A fourth crewmember will be stationed at the organizational support level for non-combat functions."

Crew Safety

The ROC dealt with crew safety in Paragraph 5t. A concern for safety was implicit in the ROC statement that "Crewstations should be designed based on good human engineering design principles." The ROC did go further and included some specific safety guidelines:

> "The system radars functioning in either a stationary or mobile mode shall not expose mounted crewmembers to energy levels greater than 10 ms/CM^2. The system shall not expose crewmembers to hazardous environmental stresses (e.g., vibration) or atmospheric contaminants (e.g., toxic waste)."

> "Peak pressure level of the impulse noise of the weapon measured at crew positions within the system should not exceed limit Y in Figure 5 of MIL-STD-1474A." (MIL-STD-1474 deals with noise limits.)

The RFP referenced the same noise standard and limit and also stated:

"The system shall not expose crewmembers to hazardous environmental stresses (e.g., vibration, temperature, or atmospheric contaminants)."

The contract specifications were more detailed with respect to safety requirements:

"3.3.6 (U) Safety. The criteria of MIL-STD-882 shall be used as a guide for the control of hazards in the design of the item. The design, materials, and construction shall conform to the safety design requirements of MIL-STD-454, requirement 1; and shall be such that all potential hazards shall be eliminated or reduced to an acceptable level. The system safety effort shall be as described in the system contractor's system safety plan.

3.3.6.1 (U) Fire extinguishing capability. The existing fire suppression system for the main engine shall be retained. Related components in the driver's compartment may be relocated if necessary. An integral fire detection and suppression system shall be incorporated in the compartment containing the gas turbine (PPU) which provides electric and hydraulic power to the turret. Fire warning, by means of a light and an aural tone shall alert the crew to the occurrence of a PPU fire.

3.3.6.2 (U) Crew safety. Ammunition storage, fuel cells, lines, pumps, and any other components containing hazardous or combustible materials shall be designed and located to minimize personnel injury as a result of fire, explosion, or detonation, whether accidental or combat related.

3.3.6.2.1 (U) Noise. Peak pressure level of the impulse noise of the weapon measured at the crew positions shall not exceed limit Y in figure 5 of MIL-STD-1474. The steady state noise level shall not exceed category B of table 2 of MIL-STD-1474.

3.3.6.2.2 (U) Electromagnetic radiation. The launch system shall not expose the operating crew or support personnel to hazardous electromagnetic radiation, when normal procedures are followed. Steady state exposure of the launch system crew shall not exceed 10 milliwatts per square centimeter when operating the system at normal stations. Hazards shall be assessed and mitigated in accordance with TB-MED-270 and AR40-583.

3.3.6.2.3 (U) Eye protection. Eye protection shall be in compliance with AR40-46 and TB-MED 279. Optical components shall not contain thorium and shall contain the necessary filters to shield the gunner from sun effects. All sighting devices shall have laser protection of 5 optical densities (50 dB) attenuation at 0.694 micron and a greater optical density at 1.064 microns.

3.3.6.3 (U) Radar interlock. The radar shall be interlocked to preclude radiation during ammunition loading operations.

3.3.6.4 (U) Laser arm switch. A laser arm switch shall be mounted on the control panel, readily accessible to both crewmembers in the turret. The switch activation shall inhibit the laser from radiating. Provisions to connect a second laser arm switch, wired in series with the one on the control panel, shall be incorporated for use by a remotely located range safety officer during test and training operations. A suitable receptacle shall be provided on the hull to connect the range safety officer's control.

3.3.6.5 (U) Weapon compartment ventilation. A positive ventilation system shall be incorporated in the weapon compartment to prevent the build up of an explosive atmosphere due to gun gas accumulation.

3.3.6.6 (U) Weapon arm switches. Each gun shall have a separate arm switch in the crew compartment, accessible to both crewmembers, to inhibit the firing of either weapon. A remote arm switch, which can be connected in series with those in the crew compartment, shall be available for use by a range safety officer during test and training operations. A suitable receptacle on the hull shall be provided for connecting these remote arm switches.

3.3.6.7 (U) Gun/turret drive control. The gun/turret drive system shall remain inoperative until activated by the crew.

3.3.6.8 (U) Crew compartment air quality. The crew compartments shall be adequately ventilated and adequately isolated from gun and engine compartments to allow sustained normal operation in non-NBC environments. The crew compartment air quality shall not be significantly degraded from that which is available outside the turret. In particular, sustained engine operation and maximum normal firing schedule employed in air defense doctrine shall not internally couple to the crew compartment's noxious or toxic

fumes in excess of the following levels when tested in accordance with TECOM TOP 2-2-614:

CO:	50 parts per million (ppm), 8-hour time weighted average (TWA)
CO_2:	5000 ppm, 8-hour TWA
SO_2:	5 ppm, peak limit
NH_3:	50 ppm, peak limit
NO_2:	5 ppm, peak limit

Peak excursions for CO and CO_2 shall not exceed the following:

10 minutes, 10 x TWA
30 minutes, 4.3 x TWA
60 minutes, 2.5 x TWA"

Human Engineering Concerns

The ROC contained the statement (noted above) that crew-station design should be "based on good human engineering design principles."

The contract specifications invoked, as guidelines, Military Standard: Human Engineering Design Criteria for Military Systems, Equipment, and Facilities (MIL-STD-1472); Military Handbook: Human Factors Engineering Design for Army Materiel (MIL-HDBK-759); and Military Specification: Human Engineering Requirements for Military Systems, Equipment and Facilities (MIL-H-46855). The contract specifications also provided additional detail in specific areas:

> "3.3.7 (U) Human performance/human engineering. The launch system shall be designed to conform with applicable requirements of MIL-STD-1472. Applicable paragraphs of the Standard are 5.5, 5.6, 5.8 and 5.9. In establishing and evaluating this conformance, human engineering techniques and procedures shall be implemented using as a guide MIL-H-46855.

The referenced paragraphs of MIL-STD-1472 deal with labeling (5.5), anthropometry (5.6), environment (5.8), and maintainability (5.9). In paragraph 5.6.4, there is a cross-reference to DOD-HDBK-743 for anthropometric data on "selected or specialized segments of the military population (e.g., Army tank crews, Navy divers, etc.)" which, according to that same paragraph, "shall be utilized for design and sizing criteria." Paragraph 5.7, Workspace Design Requirements, which was not included in the list of applicable paragraphs of MIL-STD-1472, covers areas such as cushioning for back rests and seats, normal placement of visual displays, anthropometric data for the design and sizing of work places, control placement, storage space, and seating to "provide an adequate supporting framework for the body relative to the activities that must be

carried out." Since problems arose during FOE I that were associated with each of these issues, the omission of reference to paragraph 5.7 is notable.

> "3.3.7.1 (U) Crewstations. The launch system shall provide adequate workspace for operation during a 72-hour combat period.
>
> 3.3.7.1.1 (U) Controls, instrumentation. All controls and control panels shall be arranged for sequence of operation, criticality of function and frequency of use. The squad leader's engagement controls and the driver's controls shall be accessible in both the open and closed hatch positions. The controls and displays at all crew stations shall be integrated and grouped by combat function to permit ease of executing the operational missions."

TESTS OF THE SGT YORK

Beginning in 1980 with the DIVAD Developmental/Operational Combined Test and continuing through DT IIA, DT IIB, the Sgt York Limited Test, and the Initial Production Test, the Sgt York system was subjected to a series of tests during which human factors and safety problems were identified and documented. Prior to FOE I, 68 human factors and safety deficiencies and shortcomings had been identified in the Sgt York system.

The Sgt York initial Follow-On Evaluation (FOE I), conducted in 1985, was intended to evaluate the effectiveness of that system in an operational environment, i.e., FOE I was an opportunity to observe what problems remained and what effect they had on DIVAD performance. OTEA (Operational Test and Evaluation Agency) planned the test with input from the Office of the Secretary of Defense. CDEC (Combat Developments Experimentation Center) was responsible for executing the plan. Test preparation was compromised by time limitations, by an accelerated test schedule, and by a fluctuating test plan. There were also system problems that remained unresolved from earlier tests.

It is important to understand the limitations of the field test situation as a source of inferences about battlefield capabilities. In an attempt to approach battlefield reality in the stresses imposed on the systems, man and machine, a context is created that makes it difficult to define precisely what happened when. In the case of Sgt York and FOE I, it would be useful to know what stimulus confronted each crewmember at each point in time. However, no one data base contained that information. Furthermore, integrating two different data systems, the CDEC one and the OTEA one, proved more difficult and more time-consuming than originally foreseen.

The data available from FOE I are voluminous, thanks in part to the fact that the 1553 data bus instrumentation had been incorporated into each Sgt York to supply information on hardware performance. Consequently, information on crew performance could be derived as a byproduct of that hardware instrumentation. In addition to the 1553 data, the OTEA data base included other fire unit-based data available from the audio-video recordings of crew interactions and recordings of the through-sight video pictures. Data collected by CDEC did not provide any direct information on crew behavior, but information about their actions may be derived from some of the system variables recorded.

The FOE I tests had strengths and peculiarities that make them particularly appropriate for after-action considerations. To supplement, to focus, and to provide context for the FOE I test documentation noted above, there is another important data source: the observations and conclusions of experienced human factors specialists, able to integrate and validate observations made during and immediately after test trials on relationships often obscured and circumstances often forgotten once the tests are ended, and the men and machines scattered and inaccessible.

As noted above, 68 safety and human factors problems had been identified in tests of Sgt York prior to FOE I. As FOE I began, the human factors assessment was that a problem still existed on 30 of these items. Rather than revealing the existence of previously unidentified problems, much of what the FOE I tests did was to make explicit the operational implications of the human factors problems which remained at the start of FOE I.

Inevitably, the results were influenced by the constraints of the limited trial periods and the restricted scenarios that were run. The original test design plan called for the Sgt York fire units to operate for extended periods of time, i.e., 16 to 20 hours at a stretch. Because of limits in the data recording system, trials were shortened to approximately 30-minute periods, although the crews were usually in the fire unit for another 2 to 3 hours from the beginning to the end of a given scenario. Prior to FOE I, crews had not had the opportunity to spend even that much time inside a fire unit, certainly not the 16 to 20 hours originally planned for the FOE I trials.

The Sgt York FOE I test had two phases, Force-on-Force and Live Fire. During the Force-on-Force phase, a Sgt York/Stinger platoon provided direct support for a tank-heavy task force. In addition to the 29 Sgt York trials, there were 12 Vulcan trials and 11 Chaparral/Vulcan-combined trials which were run to provide baseline data.

The actual test schedule was subject to considerable change. The FOE I Force-on-Force trials began on 2 April 1985. On 6 April 1985 a revised schedule of scenarios for the remainder of the Force-on-Force phase of FOE I was issued. Another revised schedule was issued on 17 April 1985, and another on 25 April 1985. The changes from one schedule to another were substantive. For example, the 6 April schedule shows 28 April devoted to maintenance for all units. By 17 April, two Vulcan trials, one attack and one delay, had been interposed for 28 April, and Sgt York maintenance had been shifted to 29 April, originally an OFF (rest) day. By 25 April, all units were scheduled for maintenance on 29 April; the two Vulcan trials were still listed for 28 April. On 27 April, the schedule for the next 24 hours listed not two Vulcan trials but three Sgt York trials, an attack and a delay trial in the daytime, a road march at night. On 29 April, it was reported that one Sgt York had suffered a bent gun barrel and another had had a fuel leak and fire but with no injuries. All these trials on 28 April were said to have gone well and to have met hold/scrub criteria.

Ordinarily, operational test situations are intended to establish how well systems work and to identify problems that exist. At the same time they can and sometimes do provide extensive information on details of system functioning, on how well man-machine interfaces function, on how adequate training has been for operators and maintainers, and on whether or not the tasks to be performed are within the capabilities of the personnel available for assignment to them. A major focus and result of such tests is information that can lead to system improvements and that can facilitate trade-off appraisals of different ways to accomplish such improvements, e.g., hardware changes, procedural or training changes, or personnel selection changes.

In order to obtain such information, data are collected and analyzed, much as in carrying out an experiment. However, the field test situation is in marked contrast to a laboratory experimental situation, both in complexity and in the extent to which control can be exercised precisely. Data collection in a field test situation is difficult. Often the data collected are incomplete. Operational field tests involve many more variables than laboratory situations ordinarily do, and they are concerned with more than a judgment of whether or not an experimental manipulation was effective. Operational field tests of weapon systems are carried out under conditions as near to those found on a battlefield as they can be made within limits of safety and reason, and those limits are sometimes strained as most participants will acknowledge.

In the case of the Sgt York FOE I test, steps taken to accommodate the accelerated test schedule limited the applicability and generality of the results. The personnel assigned as crewmembers were carefully selected rather than randomly

assigned; thus, they probably were not representative of soldiers that would receive such assignments in the future. There was not time to provide all the training that had been prescribed prior to FOE I, so system performance was confounded by the use of non-representative and under-trained crewmen.

Tight schedules did not allow for the unpredictable contingencies which typically plague test situations in which so much is being done for the first time. As the Sgt York FOE I tests were about to begin, the Sgt York fire units were being instrumented to provide data on performance. There was a problem with availability of through-sight video cameras. Power supplies for the Sgt York data bus recordings did not arrive on time. Battery packs were substituted as an alternate power source. High power consumption and battery pack reliability problems led to difficulties during the tests. For example, because of delays between instrumentation countdown and the actual start of the trial, battery packs on some fire units were being drained prior to the beginning of the trial.

Procedures for generating and utilizing an integrated data base were yet to be developed. Software had to be debugged. A discrepancy between the location of player aircraft and the position as reported by the fire units had to be worked out, and special validation tests conducted. Time pressures were reflected in shortened training schedules, in hastily prepared test scenarios, and in daily challenges to get the best possible information and data from a highly pressured situation.

The Sgt York Operational and Organizational (O&O) Plan (1985) specified the inclusion of three Sgt York batteries (36 systems and 45 MANPADS crews) in a Heavy Division ADA battalion. Each Sgt York/Stinger battery was to include three gun platoons and one MANPADS platoon. Each Sgt York gun platoon was to contain four gun squads; thus each Sgt York battery would have contained twelve Sgt York fire units. Since no more than four (Live Fire phase) or five (Force-on-Force phase) fire units were active simultaneously during FOE I, no exercise of operations above platoon level was planned or possible. Thus, any test of tactical employment concepts that the test scenarios provided was quite limited.

Furthermore, it is difficult to evaluate the effectiveness of tactics and doctrines of employment until crews are familiar with the system and operate it effectively, and until tacticians are familiar with system strengths and employ and deploy it effectively. Neither condition was met sufficiently for FOE I to be able to exercise or test the Sgt York system as a tactical system. Although the exchange ratio of Blue to Red forces was approximately 8 to 1 during the FOE I tests, had the troops been better acquainted with the weapon system and had the tacticians had the opportunity to go through a get-wise familiarization period, that ratio could have been expected to

improve. As it was, it represented a gain (7x) over the 57 to 1 ratio experienced by the Vulcan-supported forces.

Another issue that affected test results is related to how the crews were instructed to proceed in the face of uncertainty. The instruction provided for FOE I was that crewmembers should be sure the target to be engaged was a foe before firing upon it. As reasonable as this approach may seem to the uninvolved observer as well as to the pilot of the incoming aircraft, it introduced a definite bias into the observed results. If no questionable aircraft are engaged, some foes as well as some friendlies will escape. Thus the kill rate on foes will go down. Such a conservative approach may or may not be the most appropriate for test situations such as Sgt York FOE I, but the bias it introduces into system performance figures should not be ignored. On a real battlefield, the ability to kill incoming foes increases survival. That ability would be underestimated if judged by the performance of crews operating under a conservative decision rule.

HUMAN FACTORS DOCUMENTATION

In attempting to arrive at "lessons learned" from Sgt York, there were documentation problems that should be mentioned lest it seem that they were not recognized or were disregarded. Whether or not the items noted below were properly considered is an open question. The following considerations may have been underweighted, but they were not overlooked:

- Documentation of system development and system test and evaluation is incomplete; critical decisions were made but not recorded. Obviously, time pressures, other priorities, and the realities of getting a job done do not encourage documentation.

- No comprehensive, centralized data base existed. The documentation that does exist is scattered and difficult to list, let alone retrieve.

- Good documentation requires a great deal of work. Creating an intelligible, comprehensive record of what is being decided and what is being done can consume significant resources.

- With limited resources, the choice often seems to be between doing and recording. When something is going wrong, documenting what is happening and how it is being handled will not seem to be a top priority. It is only later that documentation will seem important, when a search is on for a key to understanding what went wrong and to preventing a recurrence.

- Real-time records of events are the most useful in terms of providing an understanding of what happened, but are the least likely to be made when the focus is on some problem.

- The abrupt ending of Sgt York added to the documentation dilemma. No one was responsible for collecting and preserving all the records, and everyone who was involved had other priorities. Neither funds nor personnel were allocated for documentation.

- Some aspects of Sgt York were considered political. In such a situation, documents are often close-held and not considered appropriate for wide dissemination. Furthermore, some things may not be documented if people feel that what they write will be distributed indiscriminately or could be presented or interpreted out of context.

- The volume of paper generated by any project of the scale of Sgt York is enormous. It would be unreasonable and inappropriate to keep everything. Judicious screening is not only appropriate but necessary: Too much, and important information is discarded; too little, and important information is buried. Either way, it is easy to lose important information. There is no fail-safe guideline, and hindsight, here as elsewhere, is better than foresight.

- Once the program was cancelled, it was reasonable for documentation suddenly to seem less useful. If little care was taken to preserve what existed or to continue to document what had not yet been recorded, that is not surprising.

The issue underlying all of these items is how to document adequately, usefully, and within reasonable constraints of resource commitment. Legal and accounting criteria aside, appropriate documentation can help to make it possible to repeat fewer mistakes and to learn more lessons from the past.

THE CASE OF VIBRATION AND PERFORMANCE

Not all issues of concern to human factors specialists were addressed during FOE I. Some issues such as personnel selection, manpower availability, and training adequacy, were to be dealt with during subsequent FOE tests. (See discussions of them in the next section.) Other issues had been treated earlier, resolved, and so are not of interest here. However, at least one issue remained that concerned a system characteristic with implications for crew safety, proficiency, and comfort. It was examined at length during the Initial Production Test; it was not a major factor to be investigated during FOE I, despite its implications for system performance and

sustained operations. That characteristic is the whole-body vibration to which crewmembers would be subjected when the fire unit was moving.

Vibration was one of the concerns called out specifically in the ROC and in the RFP for the Sgt York. The contract specifications cite MIL-STD-1472 and specifically note paragraph 5.8 of that standard as applicable. Paragraph 5.8.4 of MIL-STD-1472C specifies the limits of exposure for vibrations transmitted from solid surfaces to the human body in the frequency range of 1 to 80 Hz. These limits are specified in terms of exposure time, vibration frequency, acceleration magnitude relative to the three orthogonal anatomical axes of the human body.

The U.S. Army Materiel Systems Analysis Activity (AMSAA) Independent Evaluation of the Sgt York Air Defense Gun (IER-8-85) based on the Sgt York Initial Production Test which took place during the end of 1984 and the beginning of 1985 analyzed the whole-body vibration experienced by each of the three crewmembers (squad leader, gunner, and driver) during the operation of Sgt York over four different types of surfaces: (1) cross-country, (2) paved, (3) rough (profile 4), and (4) very rough (6" washboard). This order reflects both the probability of encountering these surfaces and the severity of their vibration effects.

When evaluating the duration, intensity, frequency, and direction of whole-body vibrations, three levels of effect were used as criteria for the AMSAA analysis:

1. The preservation of health and safety. This level is an exposure limit which should not be exceeded without special justification and precautions, even if the exposed individual has no task to perform.

2. The preservation of working efficiency. This level represents a boundary at which proficiency is decreased. Beyond this limit, exposure carries a risk of impaired working efficiency at many tasks.

3. The preservation of comfort. This level represents a boundary beyond which operations such as reading, writing, or eating become more difficult.

There is a fourth criterion level presented in MIL-STD-1472C, namely, the prevention of motion sickness, but if it was addressed during the Initial Production Tests, it was not reported in IER-8-85. During FOE I, there were incidences of reported nausea. Three gunners reported brief bouts of nausea (but no vomiting) at the beginning of long road marches (covering approximately 60 miles and taking from 3 to 4 hours). Three crews completed two such road marches during the Force-on Force trials. Two of these gunners indicated that the nausea

was not severe; they attributed the problem to being unable to see when the fire unit was going, to moving over rough, dusty terrain, and to heat and lack of fresh air. It is not clear that these problems were attributable to vibration. FOE I did not provide a basis for evaluating the effects of vibration, nor was it intended to do so.

Table 2 presents the results of the vibration tests as a way of allowing comparisons among position, surfaces, and levels. Note that safe exposure on the cross-country surface, the least damaging of the surfaces tested, was 4 hours for the squad leader, 8 hours for the gunner, and 24 hours for the driver; "operation during a 72-hour combat period" was cited in paragraph 3.3.7.1 of the contract specification, but there was no specification of period of mobility. Safe exposure was under half an hour for each crewmember on one of the rough surfaces; which surface depended on crew position. Proficiency level measures suggest that operating the target engagement system while the fire unit is moving over rough or even paved surfaces would quickly result in performance degradation.

Some of the concomitants of vibration problems were noted during FOE I. For example, the lack of padding around the squad leader's hatch combined with vibration associated with operation over rough terrain increased the hazard of operating heads-out; during FOE I some squad leaders attached a thick strip of foam rubber around their bodies at the contact point to absorb some of the shock. The need for an improved brow pad face shield, another of the problems noted during FOE I, was no doubt made more noticeable by the vibration that attended mobility.

Vibration and its consequences appeared to present major problems for extended operation of Sgt York. Perhaps the relatively brief periods of operation and mobility during FOE I obscured the impact of vibration. Also, the multitude of other problems that occurred when trying to operate and maintain several fire units simultaneously under battlefield conditions may have reduced the attention given to vibration. However, the most important factor in the neglect of this problem may have been the overlap between the schedules of the Initial Production Test (IPT) and FOE I. The IPT established safety, proficiency, and comfort levels for Sgt York and indicated that vibration might be a major problem, but FOE I started before IPT was finished and the report documenting the short maximum exposure times was not published until June 1985. Thus, the results of IPT were not available in time to inform the planning of FOE I.

CHAPTER REVIEW

This chapter reviewed the human factors requirements imposed on Sgt York. It also discussed the test environment within which human factors data were collected and issues

Table 2. WHOLE-BODY VIBRATION MAXIMUM EXPOSURE TIMES FOR SGT YORK CREWMEMBERS OVER 4 SURFACES FOR 3 CRITERION LEVELS*

		SAFETY LEVEL	PROFICIENCY LEVEL	COMFORT LEVEL
Cross-Country (10 MPH)	SQ	4 hr	2.5 hr	1 min
	GU	8 hr	4 hr	25 min
	DR	24 hr	16 hr	2.5 hr
Paved (22 MPH)	SQ	25 min	<1 min	<1 min
	GU	25 min	1 min	<1 min
	DR	2.5 hr	25 min	<1 min
Rough (Profile 4 15 MPH)	SQ	1 hr	25 min	<1 min
	GU	1 hr	1 min	<1 min
	DR	25 min	1 min	<1 min
Very Rough (6" washboards 10 MPH)	SQ	25 min	<1 min	<1 min
	GU	25 min	1 min	<1 min
	DR	2.5 hr	25 min	<1 min

*Based on Table 7.1-5 of IER-8-85.

associated with human factors documentation. Finally, it presented a discussion of a specific problem area, vibration, and its effect on crew performance.

Based on available human factors guidelines (e.g., MIL-STD-1472, MIL-HDBK-459), the Sgt York human factors guidelines were incomplete. For example, the contract specifications omitted workspace standards in listing the relevant parts of MIL-STD-1472. In view of the critical workspace problems experienced with Sgt York, these standards certainly should have been called out.

Human factors deficiencies were identified during developmental and operational tests conducted prior to FOE I, e.g., problems of workspace and visibility. Some of these deficiencies had not been resolved as FOE I began. One of these ongoing problems was vibration. Vibration was covered in the Sgt York requirements documents, and vibration tests were conducted as part of the Initial Production Test (IPT). However, the period during which the IPT was conducted overlapped that of the FOE I tests. Consequently, the test results had not yet been analyzed and published at the time that FOE I began. The IPT results indicated that vibration could have serious operational consequences for Sgt York, but no attempt was made during FOE I to assess the operational implications of the vibration problem.

The MANPRINT initiative assumes the existence of a human factors data base. Therefore, documentation during system development and system test is essential. Sgt York was not a model project with respect to human factors documentation. Indeed, as yet, there is no established model for such documentation. There are no agreed rules specifying what is worth collecting and what is not. Finally, the element of cost must be addressed. Adequate documentation is expensive; inadequate documentation may prove even more expensive. Recognizing the difference is not easy. Trial and error, flexibility, reasonable tolerance for mistakes, and constant striving to learn from mistakes and avoid repeating them will all be needed as the development of a model for human factors documentation proceeds (F. A. Muckler, personal communication, January, 1987).

IV. MANPRINT ISSUES IN SGT YORK FOE I

MANPRINT as an integrated approach to dealing with the human element in system design, development, and test is a comparatively new initiative. MANPRINT conveys a concern for Army "people problems" by focusing on six areas: (1) human factors engineering, (2) manpower, (3) personnel, (4) training, (5) system safety, and (6) health hazards. The issues that it demands be addressed are not new, but the recognition of their significance has not been universal, and their articulation and integration into the weapon system design process has been even less so. Although MANPRINT requirements were not imposed on Sgt York because the MANPRINT initiative was not in place during its development, the MANPRINT areas nonetheless provide a reasonably comprehensive set of focal points to use in evaluating the outcome of FOE I.

HUMAN FACTORS

Human factors issues are the primary focus of an earlier report (Babbitt, 1987). Twelve different subcategories of human factors concerns were treated in that report: (1) physical environment and workspace; (2) workspace, anthropometrics, comfort; (3) controls and displays; (4) workload/division of labor; (5) visibility; (6) audio and visual alarms; (7) target detection/acquisition/engagement; (8) communications; (9) travel/navigation; (10) publication/documentation; (11) safety; (12) training. The discussions contained in that earlier report will not be replicated here. Rather, an attempt will be made to provide a perspective on those problems that can be helpful in future system developments.

Human Engineering Problem Categorization

The categorization of human engineering problems identified during the Sgt York FOE I tests is not without some ambiguity. How a problem is categorized is frequently a question of what aspect of the problem description is chosen as a focus. For example, consider the following soldier-related problems. The plasma display in the Sgt York fire unit was difficult to read when there was sunlight falling on the display. Sunlight-produced glare was only a problem when the hatch was open. If closed-hatch operation had been customary and open-hatch operation a rare occurrence, glare might have been such an infrequent problem that it could have been tolerated without the expectation that mission performance would be degraded. That and other operating problems, such as crewmembers being hit by a rapidly slewing turret, were minimized when the Sgt York was buttoned down during operation and crewmembers were tightly belted in. Certain system characteristics mitigated against this mode of operation. The driver's vision was so hampered by inadequate vision blocks that he often needed the squad

leader's help when maneuvering the fire unit to avoid striking obstacles such as trees and to avoid steering the fire unit into holes. To provide such help, the squad leader frequently operated heads-out, which gave him better external vision but let sunlight into the crew compartment and made the plasma display hard to read. As Babbitt (1987) indicates, during FOE I, squad leaders spent an average 15.5% of trial time heads-out, directing drivers around obstacles and helping them navigate.

In an attempt to go beyond a listing of isolated problems which frequently appeared interrelated, and so sometimes seemed repetitive, a recategorization was performed. The result is shown in Table 3. Seventeen items were judged to be core problems and five other problems were judged derivative, i.e., secondary or occurring as a consequence of one of the core problems. These 22 problems are distributed among seven areas. There are six problems related to the physical environment, another six related to visibility (one of these derivative), five problems associated with the Sgt York displays and controls (two of them considered derivative), two (both derivative) dealing with workload, and one each related to communications, IFF, and system documentation.

The problems themselves are restatements of those identified in the earlier report on FOE I (Babbitt, 1987), and are largely self-explanatory. The derivative nature of five of the problems may merit comment.

Squad leader's periscope. Although the view from the squad leader's periscope was somewhat limited, if there had been no need to use it to navigate, it probably would have been adequate. Thus, it was not so much a problem in itself as it was a consequence of the driver's limited visibility and his need to depend on the squad leader for navigation directions.

Brake pedal. The brake pedal would not have been a problem if the driver had had room in his compartment to move his foot and leg more easily. Using the pedal was difficult, especially for larger drivers. For example, with the seat positioned fully rearward, the left side of the seat pan provided buttock-knee length room for personnel between the 5th and the 70th percentile; with the seat fully forward, only those individuals between the 5th and the 20th percentile were accommodated, according to the standards of MIL-HDBK-759A (Table 2-9).

Plasma display. The derivative nature of the problem with the plasma display is clear. It was the squad leader's operating out of hatch that led to the glare problem.

Squad leader's workload. If the squad leader had not been operating out of hatch and if he had not needed to help the

Table 3. CATEGORIZATION OF SGT YORK FOE I PROBLEMS*

Physical Environment

- o Crew compartments: hot, dirty, noisy, crowded; limited leg space
- o Crew compartments: hazardous elements; sharp edges, corners, etc.
- o Seats: uncomfortable, inadequate constraints, supports
- o Optical devices: unpadded, painful to contact
- o Storage rooms: inadequate; no place for NBC gear; marginal space for TO&E items, clothing, supplies
- o Driver's compartment: mud, water contaminated

Visibility

- o Driver's visibility: blind regions in vision blocks; near vision totally blocked
- o Goggles and driver imaging devices: inadequate
- o Driver's visibility: dust and mud obscure what little vision driver has
- o Combat crew visibility: dust, smoke interfere with target engagement
- o Night vision goggles and cab lighting: incompatible; transition difficult for squad leader
- (o) Squad leader's periscope: limited field of view, inadequate for navigation (aiding driver)

Displays and Controls

- o Auditory displays: alarms interfere with communications, distract crewmembers
- o Reset controls: poorly positioned
- o Control grips: dual controls may compete, lead to system instability
- (o) Brake pedal: difficult to operate due to space limitations, pedal contamination
- (o) Plasma display: sunlight produces glare, reading difficulty when hatch open

Workload

- (o) Squad leader: workload increased by need to help driver navigate
- (o) Gunner: workload increased when SL head-out to help driver navigate

Communication

- o Interference between external & internal communications, impact on workload, mediocre sound quality, reception problems

IFF

- o Misidentifications of aircraft via IFF system

Documentation

- o Manuals cumbersome, difficult to use

* o = Core problem (o) = Derivative problem

driver maneuver the fire unit safely, the workload of the squad leader would have changed accordingly.

Gunner's workload. Because the squad leader needed to help the driver, the gunner needed to help the squad leader.

Workspace was a problem for all crewmembers. Workspace measurements of all three crew stations are detailed in the AMSAA Independent Evaluation of the Sgt York Air Defense Gun Initial Product Test Main Report (IER-8-85). All three crew-members' stations failed to meet the anthropometric criteria of MIL-STD-1472C and MIL-HDBK-759A for workspace for 5th to 95th percentile personnel. The AMSAA report detailed the failures. The Sgt York FOE I test trials were so brief that the effects of the failures on performance were minimized. Reports of discomfort were frequent, but performance decrements were less obvious. FOE I was not designed to isolate decrements due to space restrictions from those attributable to other problems.

Each Sgt York fire unit had an audio/video tape recording all communications, internal and external, during each trial. The analysis of these recordings and the breakdown of who spoke to whom, for how long, and about what is described by Babbitt (1987). According to the planned concept of operation, the squad leader and the gunner would interact as a hunter-killer team to find and fire on hostile targets. Such cooperation could be expected to require communication between those two crewmembers. The driver's responsibility was to maneuver and relocate the fire unit, a task that would seem to require little on-going communication. However, during FOE I, squad leaders spent more time talking to drivers than to gunners. Due to limited-view vision blocks, the driver was unable to see well enough to drive around obstacles or to maneuver in close quarters without the squad leader's aid and direction. Target engagement could be delayed or hindered because the driver had critical blind spots and, needing the squad leader's assistance, distracted him from his primary task, i.e., finding and engaging hostile targets.

In the Sgt York FOE I tests, contact with external communication networks was related generally to the implementation of preplanned scenarios. Only 2.8% of trial time was spent communicating with someone outside of the fire unit, i.e., on tactical communications. Almost equal proportions of external communication time were given to squad leaders providing platoon leaders with fire unit status reports, to platoon leaders giving Sgt Yorks threat status information, and to Sgt Yorks communicating with one another about status and repositioning. Platoon leaders also talked with Sgt Yorks about repositioning, but such communications represented only 8.4% of external communications.

Perhaps because of the scenarios used and the limited number of players during FOE I, external communications did not

create a major demand on crewmembers' time. Nevertheless, during the early trials crewmembers complained about external communications interfering with their ability to perform their mission. During later trials, such communications were judged not to be a problem. An objective comparison of communications during the two periods showed no difference; crewmembers had presumably become able to deal with the additional input as they became more comfortable with their jobs and the Sgt York system. Perceived difficulties with communications reflected on level of training rather than on characteristics of the messages, or of the communication network.

MANPOWER

The impact of Sgt York on Army manpower requirements was not addressed during FOE I. For the Sgt York weapon system, crew size was not a major issue to be resolved. The ROC spoke of three or four crewmembers, the RFP said "not less than three," and the contract specifications spelled out those three as a squad leader, a gunner, and a driver. With the minimum crew size specified early and space severely restricted in both the turret and the driver's compartment, Sgt York would certainly not have required more than four (three crewmen plus an alternate) operators per fire unit, but the eventual impact of the need to operate and maintain Sgt York as it related to Army manpower requirements was not a specific concern of the FOE I tests. With MANPRINT in place, manpower impact will become a major issue with respect to operators as well as maintainers.

PERSONNEL

With any new system, there are not only questions of how well the hardware does what it was meant to do, and how well the operators are able to perform their functions, but also questions about what kind of personnel are needed to operate the system. There are also issues of what kind of training is appropriate and possible, to be considered in the next section. The Sgt York FOE I tests reveal that two aspects of crewmembers' selection are of interest: (1) ability to perform the mission, and (2) ability to fit into the space available and have enough freedom of movement to function.

Selection of Crewmembers. The Sgt York battery for FOE I consisted of two Sgt York gun platoons and a headquarters element platoon. The first platoon, crews 1 through 5, participated in the Force-on-Force phase of FOE I; the second platoon, crews 6 through 10, participated in the Live Fire phase. MOS 16L (Sgt York Air Defense Gun System Crewmember) was designated for Sgt York crewmembers. In Table 4, the rank structure authorized in the Table of Organization and Equipment (TOE), which assumed a 12-squad battery, is compared with the actual assignments for FOE I, which used only 10 crews.

Table 4. SGT YORK E-4/1 16L RANK STRUCTURE AUTHORIZED VERSUS ASSIGNED FOR FOE I

POSITION	AUTHORIZED GRADE	AUTHORIZED TOE*	ASSIGNED E-4/1
Senior Sgt York Squad Leader	E-7	3	3
Sgt York Squad Leader	E-6	9	7
Sgt York Gunner	E-5	12	10**
Sgt York Driver	E-4	12	10***

*TOE assumes a 12-squad battery.
**Five - E-5; Five - E-4.
***One - E-4; Nine - E-2.

Personnel were selected for FOE I from three sources: (1) A Btry, 4th Bn (Vulcan), 1st ADA; (2) soldiers with previous Sgt York experience (crews used on Early Production Unit Test (EPUT) and Limited Test (LT); and (3) instructors from the 1st Inst Bn (Prov), 1st ADA Trng Bde. Selections were made on the basis of a review of the Soldiers' 201 files and subsequently, in the case of those previously inexperienced with Sgt York, on the basis of performance during training. (See the discussion on Training later in this chapter.) Data on those who participated as Sgt York crewmembers are presented in Table 5. Six of the 30 crewmembers involved in FOE I were selected from those with previous Sgt York experience and so did not take part in the individual training course that immediately preceded FOE I. They are identifiable in the table by the "NA" notation in the place of an individual training score.

Prerequisites established for future 16L MOS personnel for the 16L 10-OSUT (one station unit training) course were to be active Army, in grade E-4 and below, with an OF (Operator/Foodhandler) score of 95 or above, and an EL (Electrical) score of 90 or above on the ASVAB (Armed Services Vocational Aptitude Battery). Prerequisites established for the 16L 20/30/40-T (transition) course were to be active Army, in grade E-5 and above, with a related ADA MOS, an OF score of 95 or above, and an EL score of 90 or above.

Whether or not these cutoff scores would have held up under further study is only conjecture. Data are sparse and observations suggest questions rather than conclusions. For example, among the 30 crewmen who participated in FOE I, one squad leader had an EL score of 76, considerably below the cutoff proposed for future Sgt York crewmen, and yet he completed the individual and the collective training with satisfactory scores and took part in FOE I. One gunner had scores well below the future cutoffs (OF: 84, EL: 70) but passed individual training. He did not participate in Center Certification so there is no Collective Training evaluation for him; he became the gunner on the back-up squad for the Live Fire phase of FOE I. A second gunner had an OF score (93) just below the future cutoff, and an EL score (92) just above the future cutoff; he completed both individual and collective training satisfactorily. In contrast, a gunner with an OF of 105 and an EL at the future cutoff (90) failed individual training. Another gunner with an OF at the cutoff (95) and an EL of 109 also failed individual training. Both of these latter gunners were kept on, completed collective training satisfactorily, and took part in FOE I.

The drivers' scores also suggest the limited ability of the ASVAB scores to serve as criteria. Three drivers had scores above the suggested cutoffs (OF: 101, EL: 91; OF: 100, EL: 98; OF: 99, EL: 107) and yet failed individual training. Two drivers with poorer scores (OF: 98, EL: 86; OF: 97, EL: 87) did complete individual training with passing scores (89.0 and

Table 5. SGT YORK FOE I GUN CREWS

CREW NUMBER	RANK		HEIGHT (INCHES)	WEIGHT (POUNDS)	ASVAB OF	ASVAB EL	AFQT	AND CAT	GT	TRAINING SCORES IND TNG	TRAINING SCORES COLL TNG	PREVIOUS SGT YORK EXPERIENCE
1.	SL	E-7	69	130	118	106	23	IV	108	NA	SAT	Y
	GU	E-5	73	210	105	93	19	IV	87	97.6	SAT	N
	DR	E-2	66	151	98	86	30	IV	85	89.0	Note 1	N
2.	SL	E-6	69	169	114	76	25	IV	84	91.3	SAT	N
	GU	E-5	69	130	95	109	59	IIIA	96	Fail	SAT	N
	DR	E-4	70	145	101	91	56	IIIA	99	Fail	Note 1	N
3.	SL	E-6	72	195	112	113	65	II	118	NA	SAT	Y
	GU	E-6	67	167	128	125	82	II	115	94.6	SAT	N
	DR	E-2	73	184	97	87	26	IV	80	91.1	Note 1	N
4.	SL	E-6	70	150	--	--	65	II	109	NA	SAT	Y
	GU	E-6	74	215	119	120	65	II	110	97.2	SAT	N
	DR	E-2	70	165	107	115	65	II	109	91.6	Note 1	N
5.	SL	E-6	73	196	102	109	--	IIIA	99	96.7	SAT	N
	GU	E-5	69	161	98	103	35	IIIB	80	94.9	SAT	N
	DR	E-2	69	170	108	102	59	IIIA	106	92.1	Note 1	N
6.	SL	E-7	70	160	116	125	68	II	125	96.3	SAT	N
	GU	E-5	71	155	112	97	63	IIIB	104	97.0	SAT	N
	DR	E-2	68	170	104	96	50	IIIA	96	93.8	Note 1	N
7.	SL	E-7	69	160	--	90	70	II	120	NA	SAT	Y
	GU	E-6	72	200	105	90	56	IIIA	103	Fail	SAT	N
	DR	E-2	70	164	100	105	58	IIIA	103	97.2	Note 1	N
8.	SL	E-6	66	135	--	--	80	II	120	NA	SAT	Y
	GU	E-6	70	190	93	92	27	IV	94	93.0	SAT	N
	DR	E-2	70	145	100	98	78	II	--	Fail	Note 1	N
9.	SL	E-6	70	210	--	93	17	IV	106	96.8	SAT	N
	GU	E-5	68	160	96	87	29	IV	96	NA	SAT	Y
	DR	E-2	66	142	100	98	44	IIIB	97	91.2	Note 1	N
10. *	SL	E-6	66	140	124	113	75	II	110	92.2	UNSAT	N
	GU	E-6	67	150	84	70	19	IV	89	88.6	Note 1	N
	DR	E-2	70	169	99	107	50	IIIA	100	Fail	Note 1	N

NOTES: Did not participate in Center Certification.
*Backup squad for Live Fire
OF - Operator/Foodhandler
EL - Electronics
ASVAB - Armed Services Vocational Aptitude Battery

AFQT - Armed Forces Qualifications Test Scores & Category
GT - General Test

91.1, respectively). Although none of these 5 drivers participated in Center Certification, they all were retained and took part in FOE I. Whether the cutoffs were too high or whether they just did not indicate enough about a soldier's ability is an open question, although the fact that of two drivers with exactly the same scores (OF: 100, EL: 98), one passed and one failed individual training, suggests the importance of other factors.

Table 6 compares the average test scores for each of the three Sgt York crew positions with scores for Vulcan crewmen (MOS 16R). Four test scores are included: two subtests of the ASVAB (OF and EL), plus the AFQT and GT scores. The average scores of Sgt York crewmembers tended to be higher than the average scores of Vulcan crewmen (MOS 16R). The average scores of the Sgt York squad leaders were higher than average Vulcan crewmen's scores on all four measures listed.

FOE I crews were hand picked from available personnel; due to scheduling constraints, their training was briefer than planned or desirable. Thus, any inferences made about the adequacy of the selection criteria used or about implications for future criteria must be tentative. The courses for Sgt York crewmembers were to be revised on the basis of FOE I results; assessment of the adequacy of the personnel selection procedures was planned for FOE II.

Data collected during FOE I were not sufficient to assess personnel selection criteria, but they were adequate to suggest that personnel selection procedures should be reevaluated. It is noteworthy that there were nine category IV personnel (AFQT 15-30) and three category III B personnel (AFQT 31-49) selected for the Sgt York battery. Furthermore, the individual with the lowest AFQT score, a category IV soldier, had the highest individual training score. Such an observation may have important implications for the validity of proposed selection criteria and for the specification of future selection criteria.

If category IV soldiers, or some subset of them, can complete individual and collective training satisfactorily for a system such as Sgt York and can operate such a system in a field test such as FOE I, selection criteria may need to be reconsidered. Whatever differences exist between category IV, category IIIA or IIIB, or category I or II personnel, they appear not to be the characteristics that determine applicability to weapon systems such as Sgt York. Not all category IV personnel may be appropriate for training and use as system operators, but it seems clear that at least some of them are well equipped for such an application. To presume that because a system is advanced, it must inevitably place heavy demands on the most limited personnel resources, appears unwarranted.

Table 6. AVERAGE TEST SCORES FOR SQUAD LEADERS (SL), GUNNERS (GU), AND DRIVERS (DR) COMPARED TO THE POPULATION OF 16R CREWMEN

TEST	SL	GU (N=10)	DR (N=10)	16R (N=1281)
OF	114.8 (N=6)	103.7	101.4	100.0
EL	103.1 (N=8)	98.6	98.5	98.2
AFQT	54.2 (N=9)	45.4	51.6	45.4
GT	109.0 (N=10)	97.4	97.2 (N=9)	97.9

NOTES:

OF - Operator/Foodhandler --- These are the two subsets from the Armed
EL - Electronics — Services Vocational Aptitude Battery (ASVAB) that are currently used to select Vulcan crewmen.

AFQT - Armed Forces Qualification Test

GT - General Technical

Despite the fact that there was no plan to evaluate the relative effectiveness of soldiers in different AFQT categories, and thus there were no prearranged combinations or arrangements of categories represented among the crews, there happened to be two turret crews in which both members were category II and two others in which both were category IV (see Table 5). From the preliminary evidence available from FOE I, category IV crewmen appear to perform as satisfactorily as category II crewmembers. Human factors specialists formed this hypothesis during FOE I and discussed it with a Blue Force commander. The commander's observations supported this premise. With further testing, it would have been possible to generalize beyond hand-picked crewmembers.

A more detailed and extensive comparison of the performance and interaction patterns of the subject crews might reveal additional important relationships. Such patterns could be watched specifically in future field tests of similar systems. In all future systems, as in present systems, the demand for crews and the selection of personnel must continue to be balanced within the realities of available manpower.

The multitude of problems associated with tight quarters in crewmembers' compartments could have selection implications, in addition to the performance implications already discussed. As discussed earlier, with the selection criteria that were used for Sgt York crewmembers, the driver's compartment was too small for the larger 40% of personnel. During FOE I, problems associated with space restrictions continued to be observed. One possible way to cope with limitations such as those in the M48 chassis in which personnel above the 60th percentile do not have adequate space would be to consider size as a selection criterion. Assigning only those personnel below the 60th percentile as drivers for the M48 chassis would be one approach to dealing with this continuing problem.

Selection of Maintenance Personnel. FOE I was the first opportunity for active Army personnel to perform organization maintenance on the Sgt York Gun System. FOE I personnel in MOS 24W (Sgt York Air Defense Gun System Mechanic) and MOS 224D (Warrant Officer - Sgt York ADG System Technician) were selected from maintenance instructor personnel in the SHORAD Department at Fort Bliss, TX. A comparison between the 24W rank structure that was authorized in the TO&E for Sgt York and what was assigned for FOE I is shown in Table 7.

Prerequisites for future MOS 24W personnel were to be the completion of the 16L10 course (or equivalent units incorporated into the 24W POI), a score on the EL scale of the ASVAB of at least 105, and on the MM (missile maintainer) scale, a score of at least 100. The 224D prerequisite was to have been previous qualification as a warrant officer technician for a related AD missile system, or equivalent background. Enlisted personnel were to have been allowed to qualify by (1) being selected

Table 7. SGT YORK E-4/1 24W RANK STRUCTURE AUTHORIZED VERSUS ASSIGNED FOR FOE I

POSITION	AUTHORIZED GRADE	AUTHORIZED TOE*	ASSIGNED E-4/1
Chief York Air Defense System (YADS) Mechanic	E-7	1	2
Assistant Chief YADS Mechanic	E-6	1	3
Senior YADS Mechanic	E-5	2	2
YADS Mechanic	E-4	4	1

*TOE assumes a 12-squad battery.

by the Department of the Army for warrant officer MOS 224D and (2) completing the Warrant Officer Entry Course.

Direct support (DS) and general support (GS) maintenance personnel, MOS 27P (Sgt York ADG System Repairer) and MOS 27Q (Sgt York ADG System Test Specialist), were not expected to be available before 1987. During FOE I, DS/GS maintenance was performed by contractor personnel, i.e., by Ford Aerospace and Communications Corporation (FACC).

Maintenance training, experience, and manuals were not at the point at which it would be appropriate or useful to evaluate them against the standards set up for the Sgt York ADG System by the ROC and subsequent documents. Maintenance personnel selection criteria were in a similar state. As significant as maintenance is to the operational success of a weapon system, maintenance concerns were not the focus of FOE I.

TRAINING

The Sgt York ROC (1976) noted a need "to insure that a training package of practical and effective instructional media will be available concurrently with the IOC date for the system." As reasonable as such a requirement is for good system performance, its implementation presented difficulties. Constructing training devices, preparing technical manuals, and formulating a training program is difficult when the system itself is still being developed. Start too early and much may have to be redone; start too late and elements necessary to support training will not be available in time to assure that trained crews are ready when the system is ready. In the case of Sgt York, the effort to develop training devices, technical manuals, and related items began in 1981, almost 3 years after system development began. While this late start may have been related to problems such as incomplete manuals, it was the acceleration of the FOE I test schedule that accounted for abbreviated training time.

The operator and maintainer training that preceded FOE I is discussed at length in Babbitt (1987). Because the number of training days available before the start of FOE I was limited, the Program of Instruction (POI) was modified from a planned 11 weeks, 2 days, to 6 weeks, 3 days, a reduction of more than 40%. The 16L training was conducted at Fort Bliss from 15 October to 21 December 1984 by the 1st Inst Bn (Prov), 1st ADA Trng Bde. Table 8 presents a breakdown by POI annex or component of training hours conducted for Sgt York FOE I crewmen, of hours proposed for any future Sgt York POI for MOS 16L, and the percentage of the proposed hours that the actual FOE I training represented. By comparing actual versus proposed hours, some estimate of the level of training achieved for FOE I may be inferred. On this basis, both Orientation and Fundamental Skill Building (Annex B) and Degraded and Unusual Operations (Annex I) were accorded more than 90% of the training

Table 8. TRAINING HOURS CONDUCTED FOR FOE 16L VERSUS PROPOSED POI FOR FUTURE CLASSES

TITLE OF POI ANNEX	FOE POI	PROPOSED FUTURE POI*	FOE I HOURS / PROPOSED HOURS
A. Introduction/Aircraft and Threat Vehicle Recognition	14	66	21%
B. Orientation and Fundamental Skill Building	26	27	96%
C. Operate and Maintain the M247	30	56	54%
D. Operator Corrective Actions	19	25	76%
E. Preparation for Action	11	19	58%
F. 40mm Gun Operations and Maintenance	26	34	76%
G. Feed System Operation	13	22	59%
H. Engagement Sequence	16	59	27%
I. Degraded and Unusual Operations	13	14	93%
J. Auxiliary Duties	3	11	27%
K. Range Fire	8	32	25%
L. Final Examination	24	19	126%
TOTALS	203	386	53%

*Program of Instruction (RCS ATTG-29RI), Course NO. 043-16L20/30/40-T.

deemed appropriate. At the other end of the distribution, training for FOE I on Annex A, Introduction/Aircraft and Threat Vehicle Recognition, represented only 21% of the hours to be devoted to that area according to the proposed POI. Range Fire received only 25% of the proposed number of hours.

Of 118 individual training tasks to be included in the 16L transition course, 99 (84%) were trained to the peacetime job performance standard, another 13 (11%) were trained to familiarity, and 6 (5%) were not included in the pre-FOE I resident training course. Looking at just one area as an instance, there were two separate relevant tasks (visual aircraft recognition; visually identify threat vehicles) listed among the 118 tasks. Both of them were trained to job performance standard, despite the fact that Annex A hours were barely one-fifth the proposed number. It is possible that the number of hours that had been proposed for identification training were unnecessarily high. However, one of the human factors problems identified during FOE I was misidentification of aircraft. Most of these problems were related to IFF system operation, but with or without the IFF system, misidentification of friendly aircraft appeared to be a significant problem. Training seems not to have been adequate in these cases, despite the crews having been trained to a pre-established job performance standard on the identification tasks. Whether or not the proposed hours of training would have eliminated all or most of the IFF problems, the standard used to indicate training adequacy seems not to have been adequate to the task faced in FOE I.

Of the 40 crewmen who took part in FOE I (10 crews with three active crewmen and one alternate per crew), 6 had been trained previously by FACC and did not attend the 16L course. Of 36 other personnel who took the course, 29 passed (received a final score of 90% or better) and were assigned to roles in FOE I. These 29, together with the 6 previously trained crewmen, provided 35 of the 40 crewmembers needed. Five more were needed. The battery command reviewed the scores of the remaining 7 individuals, talked with their instructors, and decided to retain 5 and return the other 2 to their original units.

Training for MOS 24W and MOS 224D maintenance personnel also was reduced from a planned 28-week course to 12 weeks and 3 days. Maintenance training was terminated before the scheduled completion date so maintenance personnel could be released to the field to get "hands-on" training during a collective training phase. Table 9 presents data on maintenance training similar to that presented for operator training (MOS 16L) in Table 8. The level of training proposed for MOS 24W is used as a standard of comparison in Table 9. No attempt was made to train MOS 27P or MOS 27Q personnel for FOE I; their functions were performed by FACC personnel during these tests.

With abbreviated training schedules, hand-picked personnel, and extensive support from FACC maintenance personnel, it

Table 9. TRAINING HOURS CONDUCTED FOR MAINTENANCE (224D & 24W) FOE PERSONNEL VERSUS PROPOSED POI FOR FUTURE CLASSES

TITLE OF POI ANNEX*	FOE POI	PROPOSED FUTURE POI (24W)	FOE I HOURS / PROPOSED POI HOURS
A. Orientation	4	4	100%
B. Solid State Electronics	0	105	0%
C. Digital Fund. & Computer Circuits	0	113	0%
D. Operation of the Sgt York	46	80	58%
E. Sgt York Organizational Maintenance	0	14	0%
F. Peculiar Support Equipment (PSE)	3	9	33%
G. System Hardware	19	18	106%
H. Power Distribution	38	74	51%
I. Hydraulics Subsystem	65	108	60%
J. Gun Subsystem	56	66	85%
K. Feed Subsystem	60	82	73%
L. Environmental Control Subsystem	15	40	38%
M. Radar Subsystem	52	93	56%
N. Optics/Laser Subsystem & Safety	40	62	64%
O. Fire Control Subsystem	36	62	58%
P. Review	28	72	39%
Q. Maintenance Management	0	23	0%
R. Final Examination	12	0	—
TOTALS	474	1015	47%

*Program of Instruction (RCS ATTG-29RI), Course No. 121-24W20/30/40-T.

is very difficult to draw conclusions about training from FOE I test results. Certainly, training plays a significant role in the effective, efficient operation of any system as complex as Sgt York, and additional training prior to FOE I could have reduced or eliminated some problems. Just as certainly, the truncation of the Sgt York training made it more difficult to determine what were basic system problems and what problems should be attributed to insufficient training time. Rather than being seen as a chance to evaluate Sgt York training, the pre-FOE I Sgt York training that took place should be seen as a way of making it possible to exercise the Sgt York system so that the system itself could be evaluated in a rudimentary fashion. Any reasonable evaluation of Sgt York training would be a later concern.

The training that the drivers received in maneuvering their fire units prior to the start of the FOE I tests was carried out at Fort Bliss. According to questionnaire data as well as on-site observations, the Sgt York crewmen found off-road maneuvering over the terrain at Fort Hunter-Liggett much more difficult and demanding than their experience and training at the flatter, more barren Fort Bliss had led them to expect or had prepared them to handle. However, even after several weeks experience during Force-on-Force trials at Fort Hunter-Liggett, the problem remained a substantial one. No amount of training can provide adequate vision through opaque sections of vision blocks.

Although the Sgt York FOE I test was not designed or intended as a way to evaluate the adequacy of training for the MOSs that Sgt York would require, it would stretch credulity to presume that level of training did not affect performance during the test. Since crew performance was in part a function of level of training, and system performance was in part a function of crew performance, evaluations of overall system performance would almost inevitably reflect training adequacy. Specific errors and problems attributable to inadequate training could sometimes be identified, but the errors in judgment and hesitations that would show only in reduced system performance are more insidious. It is impossible to adjust results appropriately to account for such confounding effects of incomplete training, but equally impossible to believe they had no such effect.

SYSTEM SAFETY

Health Hazards and System Safety are the final two MANPRINT categories. In keeping with that categorization scheme, the two issues are discussed here in separate sections. Within each section, an attempt has been made both to delineate their differences and to explore the parallels and interdependencies between them.

Differentiating the two issues from one another becomes increasingly difficult as specific problems are confronted. Among the safety problems identified during Sgt York FOE I were some that dealt with inadequate restraints (i.e., seat belts and harnesses) for all crewmen, with inadequate and unsafe workspace for drivers, and with the possibility of the drivers being struck by a rotating turret. These problems appear to be health hazards in that their first consequences are injuries to crewmembers. However, if the injuries sustained were major ones (e.g., being struck by a rapidly slewing turret could be fatal), the safety of the system could be placed in jeopardy as well.

As another specific example, the absence of a fire extinguisher in the gun bay could be a health hazard if there were a fire and a crewmember were exposed to it, but that same fire also would threaten the safety of the whole system. Incident Reports from the Force-on-Force phase of FOE I record that, on two separate occasions, a fire occurred in the lower part of the gun bay of a Sgt York fire unit. On the first occasion, the fire unit had to be deactivated.

Inadequate night vision and inadequate vision under all conditions becomes a problem of safety to the system as a whole and a health hazard to crewmembers when the fire unit must be maneuvered and the driver cannot see the terrain or obstacles within it. During FOE I, a fire unit on a night road march hit a hole with enough force to break the driver's seat belt loose from its mounting bolt; the gunner was thrown forward and injured when he struck the gunsight; the squad leader cut his elbow, requiring four stitches, and hit the plasma display with his knee, cracking the display panel. The crew continued the mission and called for medical aid at the end of the trial. The effect on mission performance would have been more notable had the trials been longer.

Night vision problems constitute an additional threat to system safety. If the driver's night vision system was to be of any use to him, the Sgt York IR lights had to be on; if the IR lights were on, the FLIR systems on the AH-64 helicopters could spot the fire units easily. Increased visibility would reduce system safety in a combat situation. The choice made during FOE I was to position the fire units at dusk and abandon the attempt to maneuver at night.

HEALTH HAZARDS

The results of FOE I indicate that the design and operation of the Sgt York system pose certain health hazards for the crewmembers. Babbitt (1987) includes health hazards as a part of the discussion of Safety Problems identified during FOE I. As noted above, prior to the imposition of MANPRINT, no explicit distinction between Health Hazards and System Safety was drawn. Indeed, most of the problems identified in FOE I as

safety issues have implications both for health hazards and system safety; they were discussed under System Safety (above). Problems with toxic fumes that had been identified during earlier developmental and operational tests and that would have posed hazards to health were resolved prior to FOE I.

The identification of potential safety and health hazard problems is an important product of engineering design analysis. Once identified, the most appropriate solution is not always immediately apparent: hardware and/or software changes, intensified training, revised procedures, or some combination of all these may be required. Subsequent developmental/operational test data are essential to check out these solutions.

For example, during the Sgt York Force-on-Force portion of FOE I, while FU 19 was being refueled, organizational maintenance workers powered up the Primary Power Unit. With the PPU there is the possibility of a hot start, i.e., a start in which flames shoot 5 to 6 feet out of the PPU exhaust. Since the occurrence of a hot start is unpredictable, it is extremely hazardous to fire the PPU up during refueling.

To deal with such a hazard, different options exist. It could be dealt with by modifying the equipment so that the PPU could not be started while fueling was taking place. Such an engineering change becomes increasingly expensive as weapon system development progresses. Hence, as production is under way or imminent, options involving procedures and training become less expensive than equipment modification. As a consequence, the later a problem is identified and dealt with, the more likely it is that it will be handled by modifying procedures and training. Standard military procedures for any refueling operation require all power sources to be powered down and grounded before refueling starts. Whether or not this procedural precaution is adequate in any specific case is a judgment that should be made following an explicit and documented trade-off study.

It may be worth noting that in addition to the incident in which the PPU was started during refueling, there were three other occasions on which refueling was performed without shutting down the PPU, contrary to authorized procedures. Three separate fire units and three different crews were involved in these four incidents. Such are the hazards of relying on procedural fixes.

V. MANPRINT IMPLICATIONS: LESSONS RELEARNED

This chapter is an attempt to articulate the lessons to be learned from Sgt York with respect to the MANPRINT initiative; to extract observations that may be useful for future systems, and particularly future FAADS developments, before they fade away; and to examine the issues identified in the light of the current MANPRINT categories and of some earlier related efforts to pull insights from experience. Sgt York has lessons that could prove useful to future systems, but earlier systems had lessons that could have been useful to Sgt York. The process seems to be one of learning lessons and then "relearning" them over and over again.

Although this review devotes more time to what went wrong than to what went right, it is in no way intended to find fault or to place blame. If problems can be identified in the context of the Sgt York weapon system and other earlier systems, it may be possible to avoid their repetition in future weapon systems. Improving system design, the weapon system acquisition process, and the Army's utilization of its human resources is the ultimate aim, and the hope is that this review will represent an incremental step in that direction.

OBSERVATIONS ON SGT YORK

In the following pages, lessons derived from Sgt York, principally from FOE I, are grouped into three categories: (1) those that are relevant to human factors and MANPRINT issues in system design, (2) those that are relevant to human factors issues in operational test and evaluation, and (3) those that are related to more general aspects of system design and development.

A full-scale reverse engineering study of the Sgt York development is probably neither appropriate nor possible at the present time. Complete documentation of the revisions in design and operational requirements, whether due to changing estimates in threat potential, to delays in achieved IOC date, or to other factors, is not readily available. Complete documentation of the details of earlier design decisions and of trade-offs made when deciding between various alternatives for dealing with identified problems (including the alternative of living with the problem and addressing it later if necessary) may not ever have been available.

An additional complicating factor was the cancellation of the Sgt York. Right after that event, many documents were destroyed. Many or even most of them may no longer have been relevant. However, it may be useful to future development projects to know what had and had not been done, and what reasoning informed the decisions.

Fortunately, there are certain key documents and data which, when combined with the observations of participants in the Sgt York FOE I tests and considered in the light of years of experience dealing with human factors issues as they relate to weapon system design, provide a rich source of useful guidance for future developments and policies. The observations noted below are not completely unique to the Sgt York nor, in most cases, are they being cited here for the first time. Note the first lesson.

Human Factors/MANPRINT in Systems Design

- System performance suffered because previous experience was neglected or disregarded.

Lessons learned from previous experience with this chassis should have been acknowledged and applied in the Sgt York development. Unfortunately, lessons learned from experience with one system are seldom applied when subsequent systems are being developed, even if some of the components or situations are very similar.

The Sgt York needed a tracked chassis as a mobile platform. The M48 chassis was selected. The M48 tank chassis has a long history; many of its limitations and problems are well known (to users, if not to designers). Much valuable experience existed in terms of both operating and maintaining that chassis. To the extent that that experience was unavailable and previous problems unfamiliar to the Sgt York designers, the new system development started from scratch. Whether the experience was undocumented, or the documents inaccessible, or the lessons disregarded, the effect was the same. Valuable experience that would have made it possible to avoid some of the problems encountered during FOE I was neglected.

More than one-third of the human factors problem areas identified in FOE I (8 of the 22 separate human factors engineering and safety problems listed in the FOE I final report) were attributable to limitations of the chassis and were, as the report notes, "inherent in the M48 chassis." The driver station did not provide adequate room for personnel above the 60th percentile. The AMSAA independent evaluation of the Sgt York (IER-8-85) anticipated this finding. FOE I documented the continuation of the problem.

Discomfort was not the only result. The brake could not be applied quickly or reliably. In addition, the driver could not see out well enough to avoid obstacles. The one positive aspect of the M48's inability to keep up with the M1s and Bradleys it was supposed to cover was that the driver's poor vision had less impact at lower speeds than it would have had at greater ones.

- o Human factors standards and requirements often do not have the impact of other system standards.

The Sgt York gun system used the M48A5 tank chassis to provide system mobility. The chassis was extended to accommodate the primary power unit and electrical and hydraulic power generation equipment; its suspension was modified because of the added weight, but no changes were made to permit the crewstation to be large enough to accommodate a driver beyond the 60th percentile. The need to provide adequate power was obvious; the need to provide adequate working space was overlooked, ignored, or rejected.

That human factors standards for working space were violated was easy to establish. Discomfort and performance restrictions due to space limitations were noted during developmental and operational tests, and they continued to cause problems during FOE I tests. With the long history of that chassis, designers need not have waited for the results of new field tests to identify problems and to evaluate either the cost of modifying the chassis to accommodate a wider range of personnel or the costs of failing to make such modifications.

Failure to meet system power requirements represents an untenable shortcoming, so it was recognized and attacked. Failure to meet human factors engineering standards is often viewed as a question of comfort rather than one of capability or level of performance. Since comfort can seem a luxury and discomfort a test of devotion to duty, human factors standards that refer to comfort may seem less realistic and less appropriate than other engineering standards.

To the extent that requirements for comfort do not take combat conditions into account, or human factors engineers do not apply human factors engineering standards judiciously and appropriately, the concern or the skepticism may be well founded. However, in many cases, the impact that discomfort and injury have on performance is significantly underestimated in field tests. Such an underestimate would contribute to the undervaluing of human factors standards. If the need for human factors standards is not reinforced and if the result of their violation is not emphasized, the significance of human factors standards will be obscured.

As noted earlier, because of limitations of test instrumentation, Sgt York FOE I trial periods were less than 30 minutes each. Crews were in their units for as much as two to three hours before each trial period but, even so, the full 3-day combat operational conditions foreseen in the ROC (1976) were not approximated. An attempt to project by some approximate factor how discomfort would become disability and would affect performance if trials were longer is aided by the AMSAA results (IER-8-85), but the nature and brevity of the FOE I trials tended to veil the importance of human factors variables.

- o MIL-STD-1472 and MIL-HDBK-759 provide design guidance that, if followed, would have reduced problems encountered in Sgt York.

The existence of adequate standards is obviously important, and every effort should be made when criteria do not exist to have them prepared, and when existing criteria are inadequate, to have them improved. However, the existence of pertinent criteria did not forestall problems with workspace, for example, in Sgt York. Criteria must somehow be made available and accessible to those who are designing the systems. The information in the standards must be made meaningful to the system design team, whether through the integration of human factors engineers into the system design team or through the system engineers' own familiarity with the standards. MIL-STD-1472C and MIL-HDBK-759A provide extensive and detailed guidelines that preclude much of the necessity for trial by error when designing a system that will have a human operator. The size and comprehensiveness of the standards certainly increases the range of their usefulness. One must wonder if those characteristics also decrease the probability of their application in specific cases. Until design engineers become familiar with the relevance of the standards to their specific design problems, the information in them may continue to be neglected and their relevance overlooked.

- o Training should not be expected to make up for design errors.

During FOE I, the Sgt York drivers had difficulty maneuvering their vehicles, particularly over the terrain at Fort Hunter-Liggett (FHL) where the Force-on-Force phase of FOE I was conducted. Drivers observed that the training they had received at Fort Bliss, where the terrain was less variable and more barren, had not prepared them adequately for the conditions they met at FHL. However, had the drivers' vision blocks allowed them an unobstructed view, the comparability of the terrains would not have been such an issue. Furthermore, it is unrealistic to expect training to allow a driver to predict when and where he will encounter a tree, a hole, or some other obstacle that he must avoid; training is hardly the answer to inadequate vision. Even after several weeks of maneuvering the Sgt York fire units during the Force-on-Force trials, experience that was both intense and relevant, the maneuvering problem remained substantial, according to post-trial debriefing comments. Training can help to overcome some of the design limitations of a system, but poor vision will remain a hazard, and its consequences should be charged to design error, not faulty training.

- o Personnel selection criteria and training requirements will interact.

If an operator has experience with a system similar to the new one he is being selected to operate, he will need less training on those aspects of the system that are comparable, but probably more on the dissimilar aspects. Positive transfer is welcome, but the possibility of negative transfer creating a demand for additional training merits attention. If the new system is to be used well, personnel experienced on systems that share some features with the new system, but do not share others, often require more training on certain aspects of the system than do inexperienced personnel.

An example of this selection-training interaction was evident during FOE I in the crewmembers choice of targeting mode. Many crewmembers had Vulcan experience, and this seemed to bias their choice of Sgt York operating mode. A commander observed after FOE I that squad leaders who were Vulcan-experienced would sometimes treat the Sgt York like a Vulcan and thereby reduce the effectiveness of the system; they would rely on laser/optics rather than radar acquisition. This commander noted that the Sgt York was more reliable and accurate when properly used than any other SHORAD system, but that operators had not yet learned to trust the system or to be aware of the redundancy that allowed it to overcome certain operational problems.

As another example, a driver familiar with any of the M48 chassis tanks with slow moving turrets would recognize the Sgt York driver compartment, but without extensive training to acquaint him with the danger of the more rapid slew of the Sgt York turret, he might find it more difficult than would a novice driver to accept the reality of the hazard of operating heads-out.

These two examples point out how one possible selection criterion, previous experience, can have an impact on training requirements. Training can be abbreviated or eliminated where the systems on which individuals are experienced are the same as the new system, but may need to be expanded where the systems are different. Other selection criteria can have implications for training as well.

Some significant selection criteria are assumed or implicit. Only when they are made explicit does their impact on training become obvious. Ability to read is one of the hidden criteria. If test scores that make up selection criteria are from written tests, as were the Sgt York ASVAB scores, poor scores may have reflected lack of knowledge of subject matter being tested, reading difficulty, or both. If reading was the problem, someone with a score well below a pre-established cutoff could have been a good candidate crewmember, capable of being adequately

trained, so long as enough of the training was experiential or was presented orally rather than in written form.

- o Manpower and personnel considerations were neglected both during design and during test stages.

It is important that concern for the human element of a system go beyond the traditional human factors engineering emphasis to include concern about what characteristics, qualities, and skills operators and maintainers of a sys-tem should have to maximize system performance, and then to consider what impact these requirements for personnel have on the larger question of manpower availability.

Unfortunately, time pressures during design are often such that there is insufficient time to consider basic task design adequately, let alone to look at the implications of that design for personnel or manpower aspects. Furthermore, it should not be presumed that all that is needed is for the significance of such issues to be recognized. Even given awareness of their importance and time to address them, the question of how to translate system functions or tasks into personnel characteristics is not a matter of turning a crank or consulting a table. There are problems in making such translation that are only beginning to be addressed and that will continue to challenge human factors engineers for some time to come.

As noted earlier, personnel selection criteria for Sgt York were not evaluated during FOE I, but data collected and observations made during that test indicated that personnel selection criteria needed further attention and should be reevaluated. Personnel whose scores on ASVAB subtests were well below the proposed cutoffs completed individual and collective training for FOE I satisfactorily and went on to participate as crewmembers. Other individuals who met the established criteria on the ASVAB subtests failed the individual phase of the pre-test training. Two individuals had exactly the same criterion scores; one passed and one failed individual training. The individual with the highest individual training score had the lowest AFQT score.

The imposition of MANPRINT requirements may increase the sensitivity of design engineers, of system evaluators, and even of human factors engineers to personnel and manning issues as they relate to system complexity, ease of operation, or ease of repair. To the extent that MANPRINT develops awareness at a point in system development when choices are being made that influence later personnel selection, to that extent it may allow the realities of manpower and the characteristics of personnel to influence system design. Good human engineering design decisions can make the system easier to understand, easier to learn, and easier to fix. The resulting system may reduce demands on personnel without being a poorer system.

After design, development, and extensive testing, "people problems" remained. In addition to undefined operator problems and maintenance and maintainer difficulties, the Sgt York system had questionable selection criteria, there were unsettled as well as unrecognized training issues, and no careful consideration had been given to the effect of total manpower demands of the Sgt York on Army human resources.

- Establishing crew size prior to system development may place an unnecessary constraint on system design and may prejudge personnel issues.

As noted early in Chapter III, crew size was set at no less than three crewmembers. One crewmember was assigned as a driver and two were assigned target engagement functions. The sophisticated automatic target search, identification, and prioritization system developed for Sgt York provided extensive support for target engagement functions. Although the issue of crew size was not a focus of investigation, or a subject on which crewmembers typically were questioned, spontaneous comments by crewmembers in both squad leader and gunner positions indicated that at least some of them believed a one-man Sgt York target-engagement operation would have been possible. Some of them added the observation that the operator in that case would have to pay particular attention to the plasma display.

Since no attempt was made to deal with the range of tasks necessary to assure continued operation over an extended period (i.e., with questions such as the possible conflict between engagement monitoring and ammunition reloading), an observation at this point can only note an unexplored area. However, had a two-man vehicle been feasible, the positive impact on life-cycle costs and on manpower, personnel, and training demands would have been considerable had the system been fielded.

- Design realities and tactical concepts of operation must be consistent if a weapon system is going to be able to be used as projected.

This was not the case with Sgt York. There was a basic incompatibility between the concept of operations for the Sgt York weapon system and the design implementation of that system. The turret crew was to concentrate on engaging hostile targets; the driver was to be responsible for system mobility, for getting the fire unit where it was needed, safely, efficiently, and independently. For this task allocation to be effective and implementable, the driver had to be able to see where he was going well enough to maneuver the vehicle and avoid obstacles. As FOE I trials made clear, the driver could not see well enough to maneuver without the squad leader's aid.

Visibility was particularly poor at night. Night operations were so hampered during the first night trial that, during the

second night trial, night mobility was abandoned in favor of pre-stationing the fire units at dusk to approximate the second night trial scenario.

Without some way of improving the driver's ability to see, by day or by night, the Sgt York could not be expected to be as mobile and as maneuverable as its concept of operation demanded. The tactical scenarios played out in FOE I were designed around Sgt York's imagined capabilities rather than its actual strengths. Whether or not a modified concept of operation would have been developed to exploit the qualities that Sgt York did possess was a question left unanswered.

<u>Human Factors in Operational Test and Evaluation</u>

- o Judgment, experience, and good data are needed to separate the effects of system design, personnel selection, and training when viewing system performance.

As noted earlier, it is often not easy to differentiate the effects of inadequate design and incomplete training. Indeed, the two are not clearly separable. The adaptability and trainability of human operators and maintainers have long allowed them to accommodate to some degree to system design that is less than ideal. Good system design should reduce demands on training, just as training can compensate for some design problems that may have been overlooked until late in the design cycle and have become too time-consuming or expensive to fix. Operators can be taught to work around certain design problems. Personnel selection can help to ensure adaptability and resourcefulness. Human factors, training, and personnel specialists can help in making judgments, and in identifying the judgments that need to be made. They can also identify what data are needed to support such judgments before they are made and to verify them later. Good data can confirm the human operator's ability to cope with a flawed design and can establish the amount of training required to do so.

Although Sgt York was designed to have two crewmembers concerned with target engagement and a third, the driver, concerned with navigation, the system did not provide adequate visibility for the driver. The flexibility of the crewmembers allowed them to compensate, at least partially, for this design flaw. The workspace problem points up another interaction: inadequate space may be viewed as a design problem or as a personnel selection constraint. As noted earlier, selecting smaller crewmembers would have reduced the impact of workspace problems on performance.

- o Analyses should be performed and presented in the same terms stated in requirements documents.

For example, the daily operator/crew check time requirement was stated in terms of a maximum standard that should be met a

stated percentage of the time. According to the ROC (1976, p. 7), "Daily operator/crew checks and services should require no more than one hour 95% of the time." The results of the analysis were presented in terms of the mean time required to perform the checks rather than in terms of the percentage of time the standard had been met. In the discussion of the results, the mean time was broken down by fire unit and standard deviations were also provided. The presumption that the requirement was reached satisfactorily appeared reasonable from the mean time obtained: that is, the mean time was low enough for it to seem reasonable that 95% of the individual measures had been below one hour. With the inclusion of the standard deviations such a presumption appeared even safer. However, if both the requirement standard and the test results were stated in directly comparable measures, no inference would be needed to be sure that the requirement had been met.

- OT&E performance test data may reflect incomplete training rather than a design flaw or a personnel selection problem.

As discussed above, during early trials of the Force-on-Force phase of FOE I, crewmembers complained about communication problems. There were some delays in movement because drivers could not hear. During later trials, communication was no longer considered a problem, but the communication had not changed; the crewmembers simply had become able to deal with the communication load through experience and practice.

As another example, during DT IIA, crews were confused about the direction in which the conveyor belt should move for load or feed operations. Among the recommendations made for dealing with the problem was that decals be placed on the magazine to indicate direction of movement, with additional decals as reminders that "load" referred to the magazine and "feed" referred to the gun. However, FOE I established that training eliminated the problem and no further fix was necessary.

Thus, sometimes problems identified during early trials can be seen more reasonably as a training problem than as a design problem. The opportunity for data to accumulate to permit such a judgment is one reason for having operational tests extend over a sufficiently long time. How long is long enough is a not-insignificant judgment.

As already noted, the training that preceded FOE I was cut short to meet revised test schedules. Crewmembers, as well as human factors specialists, recognized that the training was too short, and that it should have included actual experience with ECM (electronic countermeasures). Crewmembers comments indicated that the descriptions provided during training had not readied them to deal with all the ECM situations they encountered during FOE I.

- o Training support elements need to be ready and in place if the training conducted prior to OT&E testing is to be adequate.

It is difficult to evaluate the impact of missing and inadequate support elements, but there is little doubt that the shortcomings of training will be reflected in system performance during test. In addition to the fact that training prior to the Sgt York FOE I was too short and included too little hands-on experience, there was not enough Mission Oriented Protective Posture (MOPP) clothing available for all crews to be able to practice actual NBC drills, the equipment and procedures needed to clear round jams were not available, new loaders used in reload training did not fit, the classroom trainer was not realistic, the maintenance manuals had many blank pages, and frequent changes were made in course material during the actual training. In their comments, crewmen noted that some students had had more experience on the Sgt York fire unit than had the instructors.

- o For operational tests to present a realistic picture of system performance, that performance must not be obscured by shortcomings in the support categories.

The support elements, the test equipment, the peculiar support equipment, the training devices, the technical manuals and other provisioning components need to be developed in parallel with the system so that when the system is ready for operation test, the support needed for it is also ready. As discussed earlier, support for FOE I was a problem, particularly with respect to training which was rushed and insufficient. During maintenance training, some peculiar support equipment (PSE) items were not available or did not have the safety releases necessary for their use by military personnel. The use of these items was covered in conference instruction, but hands-on instruction or practical exercise training with them was not possible. The shortage of technical and training manuals during FOE I was called "grave" and "a serious problem" by participants. The peripherals may seem less significant than the system itself, and so their development may seem less urgent.

From one perspective, the development of system adjuncts can be considered less pressing. If the system passes the operational tests, it will still be some time before it is actually fielded. During this interim period, the training curriculum can be refined, the training and operating manuals prepared, the training conducted, the peculiar support equipment provided, and similar support components considered and completed. To postpone initiation of the development of this support until the system is in production could delay the operational date of the system, so it is important that support development be begun as soon as system design is firm enough to make it practical.

However, there is another consequence of delayed development of the support elements that is easily overlooked. Without adequate support, without thoroughly trained operators and maintainers, system performance suffers. To the extent that system performance is affected during operational testing, the system will not operate to its full potential. System evaluation will be negatively biased by factors that pertain not to system characteristics but to quality of support. Inadequate support never improves system performance; it can easily degrade it. Satisfactory support must be provided if system performance data collected during OT&E is to reflect true system capability.

- o For system performance measures (such as number of kills or number of accurate identifications or appropriate break-offs) to be reliable, information about the state of the world as well as information about crew actions must be available and accurate.

One of the major problems encountered in analyzing the FOE I data was in determining what targets actually were visible to a Sgt York crew when they were engaging targets. Since the aircraft (in the case of the Force-on-Force phase) or drones (in the case of the Live Fire phase) were not connected to the 1553 data bus which supplied data from individual Sgt York fire units, the question of what actual target was in view when a crewmember was pointing, designating, or firing on something could not be resolved by recourse to that data source. It proved difficult to correlate the CDEC data base, which did contain range aircraft position data, with the 1553 data base. Through-sight video recordings provided help in correlating targets, but it was a difficult, time-consuming procedure. A correlated target was one that was judged to have been a real, rather than a false, target; that is, the target displayed was judged, either on the basis of range instrumentation data or from the through-sight video recording, to have correlated with an actual aircraft.

In FOE I, there were 767 fixed-wing display engagement opportunities; that is, in 767 cases there were correlated threat targets within range (less than 6,000 meters distant) that were displayed to the crew long enough for them to be engaged (for at least five seconds plus time of flight for the range of the target). There were 114 rotary-wing display engagement opportunities. The rotary-wing instances were examined individually by means of plasma display and through-sight video recordings to determine the doctrinal soundness of the crews' actions, but the more numerous fixed-wing cases were not examined in the same depth. Differences in crew performance as a function of target-type (fixed-wing vs. rotary-wing) would be of interest, but without a case-by-case examination of performance against fixed-wing targets, no valid comparison of performance was possible.

- Crew performance data collection should not be an afterthought; it should be preplanned and provision made as the system is designed and built.

Despite the difficulties encountered in calibrating data from the 1553 data bus to that from other data sources and to the outside world, the significance and usefulness of the 1553 data should not be overlooked or minimized. Having such a source provided important objective crew performance data.

Improvements in the data record are needed to render it more complete. Crewmembers made judgments that were not recorded and that could have helped to explain what happened. Crew performance recordings should be part of early planning, not accidental. In the case of Sgt York, having crew actions reflected on the 1553 data bus was a fortunate by-product. As noted earlier, the 1553 data bus had not been designed to collect crew performance data but only to provide data on hardware. If crew performance data collection needs had been considered before test planning began, a more complete record could have been obtained.

Nonetheless, the 1553 data were very important. Crewmembers' actions became part of the 1553 data record and did not have to be inferred or observed; they were recorded and thus recapturable as long as the records are preserved. Future FAAD systems should not neglect the need for even better data recording. Measurement technology is available to measure both crew and system performance precisely. The cost of that technology may deter its use in individual systems; but without these data, it is impossible to reconstruct what actually happened.

- An adequately detailed test plan needs to be available before the start of the test so that the human factors observer will know where he needs to be, when he needs to be there, what he is to measure, how the measurements are to be taken and recorded, what instruments will be needed and available to take the measurements, and how the data, once recorded, are to be analyzed and reported.

Test plans for Sgt York were still being formulated as FOE I began. During the test, there were frequent revisions in trial schedules with respect to the air defense systems to be involved, the scenarios to be followed, the tactics to be employed, and the ECM conditions to be used.

Procedures for data collection and reduction were not set or checked out as FOE I began. The format of the records on the position location data tape was not as expected on 2 April 1985, so software to read the new format had to be written as the test proceeded. Data processing and analysis continued to present problems throughout the test.

Instrumentation was another element not in place in time for it to be checked out adequately prior to the beginning of the trials. Once the instrumentation had been installed, there were problems with camera, recorder, and tape failures. There were also procedural errors: in some cases, recording was not started at all; in others, recording was started too early and the tape ran out before the trial ended. There was particularly severe data loss from certain fire units, so a microprocessor chip was changed, but not until the second week of FOE I.

All these problems resulted in substantial loss of data during early FOE I trials. Data discrepancies discovered and worked out during the trials should have been resolved before FOE I began. Test plans and preparations had not been complete when FOE I started. As a result, during the test, resources were stressed, efficiency was decreased, and cost was increased.

System Design and Development

- A written record of weapon system development would be very useful during evaluation of that system and design of future related systems.

If a systematic, accessible record of information relevant to each system development were maintained, it could include events, dates, decisions, requirement statements, and document trade-off study considerations and recommendations. What alternatives were considered when trade-offs were made may seem irrelevant once a decision has been made about how to proceed, but such decisions have long-term effects. If a decision is made to rely on training, or on information in a manual, or on a label, rather than redesigning a component, follow through is important. Later tests should assess the success of the chosen fix. If projected solutions failed to be effective, advocates of relying on them in the future might review their assumptions.

A record of what was done, what was anticipated, and what really happened could be useful in shaping future judgments as well as explaining past ones. What may seem a reasonable or even an obvious choice at one stage in the weapon system acquisition process, in the light of later experience or developments, may appear either short-sighted and ill advised, or fortunate and appropriate, depending on the case. Unfortunately, keeping a record that would allow such a review would entail immediate costs on a current contract; any benefits would be in the future and often on a different contract. Not only the costs but the risk in recording trade-off decisions may be clearer than the gain. A record might reveal a fallibility in judgment or care that memory alone would obscure.

Often earlier decision processes are reconstructed so that they better fit with information gained after the decision was made. A trade-off study represents an attempt to systematize decision

making and to minimize the size of the inferential leaps that are made when seeking tolerable compromises in the face of problems that have no easy resolutions. Keeping a record that documents trade-off studies, or documents the failure to recognize the need for a trade-off study, can provide a reminder of the slow and incremental nature of system development. Documenting what was known when may make it easier to perceive how much has been learned, to appreciate the increment, and to tolerate tardiness in recognizing what ultimately became obvious.

The current endeavor to create a data base for continuous and comprehensive evaluation (C^2E) of a system as a way of tracking developments, problems, and fixes is an attempt to capture system-relevant data and more. It is an effort to create a record of a system that would allow system assessment on an ongoing and up-to-date basis. If successful, the implementation of such a C^2E data base would permit problem identification in the subject weapon system and would also facilitate the recognition of possible parallel problems in other systems which use the same or closely related components. Eventually, a network of such system data bases might be constructed that would permit a review of hardware elements being considered for use in new systems to see what problems had attended their use in earlier systems.

- The carry-forward of problems from one system to another and from one stage of development to another is inadequate or nonexistent in many cases.

Past records are lost, incomplete, or neglected, and as a result lessons that could be learned are lost, and modifications that could be made inexpensively at early stages are not salient, noticed, or acknowledged until long after they should have been attended to. By failing to look at the history of the system itself, design lessons are neglected.

It is even more rare to consider similar types of systems and to draw lessons from the history of development and the problem experience of related systems. As noted earlier, much valuable experience exists in terms of both operating and maintaining the M48 tank chassis. Without documentation and retrieval of that history, each new system development in which that chassis is used has to start from scratch. Some of the problems encountered may be new ones that arise because of the specific use to which it is being put and the specific other components with which it is integrated, but many other problems have a long history of occurrence, and it is unfortunate that that history has not been captured and put to some positive use. In the case of the Sgt York, the most positive use of information on the M48 chassis might have been to encourage the selection of a different chassis for the new system.

Early in the weapon system acquisition process, an overview of design problems needs to be considered and a search for parallel problems and alternative resolutions made. Reliability engineers, human factors engineers, and system engineers all need to be involved in such overviews. It should have been possible to foresee many of the problems before the only choices were system performance degradation or a very expensive design fix. The solutions decided on as a result of the trade-off studies performed during design may not have been the best or the only solutions. If such trade-offs could be reconsidered in light of subsequent experience, new requirements, new techniques, and current resources, the insights gained might have a very positive influence on the whole design effort and ultimately, of course, on the quality of the system produced and the level of performance eventually achieved.

When Santayana said that those who are ignorant of history are doomed to repeat it, he may have been speaking of political history, but it is equally applicable to the weapon system acquisition process. The more it is possible to capture the history of a system and reduce it to a form in which it can be transmitted to other designers when it becomes relevant, the fewer the mistakes that will have to be repeated.

- o "Accelerated procurement" or "accelerated development" can reduce the quality of the product even though it was only meant to reduce the time needed to produce it.

In this report, the Sgt York procurement has been called "accelerated." Certainly, the test schedule was accelerated. That the system development was also accelerated may be in part a judgment, but it is based on the schedules established and attempted. The ROC was issued in September 1976; it called for "an Initial Operational Capability (IOC) by CY 1980. The first battalion IOC is required by 1983."

Having set the target date for initial system operation, the ROC also assessed that schedule (paragraph 6.c., p. 8): "The CY 1983 IOC is reasonable, attainable, and a low to medium risk approach. The CY 1980 IOC, however, is a high risk approach." Since the 1980 date was for the first unit and the 1983 date for a battalion, the assessment of the 1983 IOC as reasonable was perhaps contingent on achieving the 1980 IOC. That is, if a unit reached IOC by 1980, then a battalion IOC date of 1983 was reasonable.

The four years between 1976 and 1980 represent half of the average weapon system development time of eight years. By the time the RFP was issued (April 1977) and the initial contractors chosen (January 1978), a period of 29 months was left for system development. Whether or not this schedule was officially considered accelerated, it was unusually brief; i.e., it was considerably shorter than average weapon system development time.

The additional pressure inherent in such a development process has special implications for human factors engineering and for all of the MANPRINT concerns. It is difficult enough to assure appropriate attention to human factors concerns under normal development pressures.

Whether these concerns be ease of operation or maintenance, ability to sustain high quality performance over extended periods, or the wide range of other human factors issues related to weapon system development, the relationship they have to questions such as personnel selection, trainability, and safety, and ultimately to system performance, is less obvious, less direct, less measurable than the impact on system performance of power adequacy, radar reliability, or ranging accuracy. The more distant the relationship, the more likely its consideration will be postponed, neglected, or otherwise undone.

The more complex the weapon system, the greater the risk that more will be lost than gained by attempts to accelerate development. Making a decision to use off-the-shelf equipment and to combine it as effectively and quickly as possible into an operational system seems a conservative, economical approach at first glance. It may seem a shortcut, a way to save design effort, but component incompatibilities must be recognized and dealt with. Interface problems should not be minimized in planning; they will not be in practice. A realistic view of development must take into account the modifications necessary to make previously unrelated components work together compatibly. Interface details may seem insignificant, but resolving them is essential.

Working around inconsistencies may be more time consuming and hazardous in some instances than avoiding them by using a new design. Modern weapon systems are not composed of plug-in compatible components. Early trade-off studies of the cost and complexity of working with available components and their necessary modifications versus the time and cost of using new components are difficult to carry out. Difficult as it is to assess the speed with which compatibility of components could be achieved, it is even more difficult to project accurately how long it would take to design new components. However, if state-of-the-art concepts are specified, the estimates will be shorter and more accurate than if a requirement exists to stretch the state-of-the-art. At any rate such a comparison of costs, however tentative, is needed as a foundation for decisions about using off-the-shelf components. Minimizing developmental complexity is possible without using off-the-shelf hardware. State-of-the-art design need not mean using only off-the-shelf hardware.

- The form in which requirements are stated is important.

If a requirement is stated in quantitative terms, it provides more explicit direction for design engineers and a more precise criterion for system evaluators. A series of studies sponsored by the Air Force almost two decades ago (Meister, Sullivan, & Askren, 1968; Meister, Sullivan, Finley, & Askren, 1969) demonstrated this relationship. If a requirement is stated in non-quantitative terms, the question of whether or not it is met demands (or allows) a different kind of judgment. It is more difficult to establish that a requirement of the form "follow good design principles" has or has not been met.

Some way of handling the broader, more encompassing nature of non-quantitative requirements also must be developed if neglect of human factors issues early in the design process is not to continue. Problems seldom disappear because of neglect. Until requirements are interpreted in terms of existing standards, and until failure to attend to them has consequences before the system is fielded, general "good design" requirements will continue to be in danger of being neglected or misinterpreted.

As an example, the ROC (1976) noted as item "u" under paragraph 5 (Essential Characteristics), that "the burst signature and smoke obscuration of the cannons must be minimized such that the gunner can conduct his mission in the optical mode." During FOE I, there were visual problems in target detection, acquisition, and tracking that involved the effects of smoke and dust. This problem troubled three different crews and was confirmed by through-sight video recordings. The Live Fire trials note that targets were sometimes obscured by dust and smoke, especially during long bursts.

Problems such as these may only become apparent during field tests. To expect that every eventuality and interaction can be foreseen before that point is unrealistic; systems will continue to present unexpected problems. By minimizing preventable problems, energy and time available during and after operational tests can be channeled more appropriately.

- Requirements freezes are essential no matter how difficult to implement.

As frequently happens with a system when the acquisition process extends over several years, the design requirements are modified from time to time. The reason is both obvious and understandable, but the implications of such changes may not be as clear. For example, the ROC (1976, p. 4) states that the system should be capable of detecting fixed-wing threat aircraft "out to ranges of 10 to 15 km" and rotary-wing threat aircraft "out to ranges of 7 to 10 km, assuming line of sight." Further, it was to be able "to permit accurate engagements out to projectile intercept ranges of at least 4 km." After target detection an "aimed initial burst" was to be fired "within 5 or

6 seconds." The rotary-wing threat the system was tested against during the Force-on-Force trails was at 6 km.

If threat characteristics (or, more accurately, intelligence estimates of those characteristics) change, it seems only reasonable that the weapon system under development be asked to keep up with the change. Producing a system that is obsolete almost before it is fielded is inappropriate and wasteful. However, if a change in requirements calls for a time-consuming change in weapon system design, it may result in the system being farther outdated than it would have been without the change. (If, for example, updating a system by two years in terms of threat capability slows production delivery by more than two years, there is a net loss.) If the additional obsolescence is noticed in time, another modification could be mandated. The weapon system design theoretically could continue to chase the threat and never be frozen long enough to be produced.

EARLIER REVERSE ENGINEERING AND DESIGN CRITERIA STUDIES

During the early 1980s, several case studies of the development of specific weapon systems were conducted (Arabian, Hartel, Kaplan, Marcus, & Promisel, 1984; Daws, Keesee, Marcus, Hartel, & Arabian, 1984; Hartel & Kaplan, 1984; Kane, 1981; Kane, Bean, & Kirchner-Dean, 1986; Marcus & Kaplan, 1984). As Johnson (1986; p. 3) notes, the purpose of these studies was "to determine how man was considered as a design element in the acquisition process and the relationship of people factors to the field performance of the weapon system."

Such case studies have led to the identification of explicit deficiencies in considering man as a system component and in integrating human performance into the total operational performance of a fielded system.

As a follow-on to the reverse engineering studies, the Army Research Institute (ARI) produced a series of reports entitled "Human Factors Engineering Design Criteria for Future Systems." The purpose of the series was to examine the adequacy of existing design criteria and the relationship of these criteria to problems encountered in various component systems during operational tests. Their relevance to Sgt York makes them worth reviewing at this point. Had the "lessons learned" from the systems discussed below been put into practice, Sgt York could have benefited, and the lessons would not have had to be relearned.

M1

The M1 Abrams battle tank was the subject of the first of those design criteria reports (Earl, 1984). Design problems encountered during M1 OT II were reviewed in conjunction with

MIL-STD-1472C and MIL-HDBK-759A to see how adequate the criteria were.

It was found that approximately 80% of the HFE problems common to both the M1 tank and previous similar systems "are covered by current criteria which provide adequate guidance for resolving such problems" (Earl, 1984; p. vii). Such problems, i.e., problems that were not unique to the M1 but were holdovers from earlier, similar, and similarly plagued systems, made up three-quarters of the HFE problems encountered with the M1 tank. Earl noted that these problems, which comprised the majority of the HFE problems with the M1, "could have been avoided had greater emphasis been given to adhering to requirements established by current criteria" (1984, p. vii) or, it might be added, by reviewing problems encountered by users of similar earlier systems. Similar conclusions are appropriate in the case of Sgt York: chassis problems should not have been unexpected; workspace criteria exist but were not met.

In the other 20% of the cases of holdover problems common to the M1 and earlier systems, criteria which should have covered these problems were judged to be "inadequate design criteria that did not provide the required information" (Earl, 1984, p. iii). Revisions for these criteria were proposed in the report. Sgt York problems have not been subjected to an analysis that would permit a similar quantitative assessment.

In the case of the components new to the M1, only 54% of the problems associated with them were covered adequately by existing criteria. For 36% of the new-component problems, criteria existed but were inadequate. Only 9% of the problems with the new components had no criteria at all to provide design guidance. A new-component analysis of Sgt York problems was not completed.

FIST-V

The Fire Support Team Vehicle (FIST-V) was the subject of the second report in the series of design criteria studies (Crumley & Earl, 1985). HFE problems identified during FIST-V OT II were related to 27 different features or components of the system. Current criteria were available for all of the problem areas identified and in only 2 of the 27 features were the criteria considered inadequate. In other words, guidance was available to prevent a majority of the problems that remained to be identified during OT II. Obviously, the Sgt York system was not unique in exhibiting problems that were preventable had existing criteria been followed.

A closer look at the problems which arose in the FIST-V revealed that by far the greatest proportion of them involved the configuration of the crewstation. Twenty of the 27 problem components concerned the design, layout, and arrangement of the crewstation. This group included problems with workspace,

seating, location, and arrangement of controls and displays, visibility or illumination of displays, and safety considerations. It is interesting, in the light of Sgt York experience, to note that the FIST-V was a modification of the M901 Improved TOW Vehicle, itself a retention, almost unchanged, of the M113A2 hull. Again, a new system was imposed on an existing crew compartment, retaining the problems of that compartment.

MLRS

The third system to be subjected to the reverse engineering process was the Multiple Launch Rocket System (MLRS) (Arabian, Hartel, Kaplan, Marcus, & Promisel, 1984). Two vehicles comprise the MLRS: Self Propelled Launcher Loader (SPLL) and Heavy Expanded Mobility Tactical Truck (HEMTT). According to the design criteria study (Earl & Crumley, 1985), current criteria cover all the HFE problems identified in the MLRS OT III. In the SPLL portion of the system, existing criteria were adequate in 78% of the cases; in the HEMTT portion, existing criteria were adequate in 82% of the cases. As Earl and Crumley summarize the situation, "adequate design guidance is available in current criteria to avoid most of these problems in future MLRS systems."

The most frequent problems on both vehicles were concerned with seating, workspace, stowage, and illumination systems. The first three are elements of comfort considerations in the operator stations. It appears that this outcome occurred because the designers did not take into account the long time periods in which the crewmembers must occupy their crewstations when performing the MLRS mission. Similarly, the many problems with the illumination systems in the two vehicles appear to be due to a failure to appreciate fully the operational conditions under which they are used" (Earl & Crumley, 1985, p. vii). A similar comment would be appropriate to Sgt York problems associated with glare on the plasma display and with lack of adequate illumination for reloading operations.

Reflecting on these conclusions, that designers failed to take into account long operating periods and actual operational conditions, one must also be concerned that the impact of workspace problems that arose during the relatively short FOE I trials to which Sgt York crews were subjected would have affected system performance much more seriously had operations more closely approached the "average combat day operation for a consecutive 3-day 24-hour period" projected in the ROC for the Sgt York (1976).

The findings of the MLRS reverse engineering study appear directly relevent to the case of the Sgt York. If Earl and Crumley (1985) "provide much of the information necessary for correcting the current HFE problems on the MLRS and preventing the recurrence of similar problems in future generation systems" (p. viii), then some consideration needs to be given to

making such information available in a way that can improve future systems. Sgt York would have benefited had existing information and criteria been used.

Stinger

The fourth system subjected to post-facto review was the Stinger (Daws, Keesee, Marcus, Hartel, & Arabian, 1984). In this case, the results pointed to ineffective allocation of tasks between machine and operator, to task sequences too complex to be readily learned or accurately remembered, and to demands on human capabilities that do not match well with the characteristics of the personnel available to fill them.

The parallels between these conclusions and those applicable to Sgt York, at least on the basis of experience provided by FOE I, are not exact. In Sgt York, the problem of task allocation was not between machine and operator but, as discussed earlier, between operators. The target engagement sequence called for well coordinated interactions between the squad leader and the gunner; confusions did occur, but analyses performed were not sufficient to fault the allocation of tasks or the complexity of sequences. Also, as noted earlier, the squad leader was called on to help with vehicle navigation. Thus, the characteristics of the machine affected task allocation, but the relationship differed from that identified by the Stinger analysis. So far as the tasks placing inappropriate demands on personnel, the circumstances of FOE I were not designed to allow the characteristics of the personnel to be assessed with respect to the characteristics of the tasks to be performed.

While the proportion of avoidable problems varies from system to system, it seems clear that there is at least as much problem with criteria not being applied as with their not existing. (See Table 10.) In far too many instances in these cases just reviewed, as well as in the case of Sgt York, had existing criteria been followed, the resulting systems would have had far fewer problems. To conclude that they would have been better systems may represent a challengeable step, but it is certainly no great leap of faith.

MANPRINT AND THE FUTURE

The reverse engineering studies documented problems that were easier to recognize than to fix. In attempting to take the step from recognition to resolution of these problems, General Maxwell Thurman (Vice Chief of Staff, U.S. Army) sponsored the MANPRINT initiative discussed in Chapter IV. The concerns are not new, and MANPRINT is not the first attempt to improve the systems that are developed by looking early, in depth, and in context at the impact of human factors on systems. Prior efforts to integrate the consideration of such factors into the weapon system development process can be

Table 10. SUMMARY RESULTS FROM EARLIER DESIGN CRITERIA STUDIES

	CRITERIA ADEQUATE	CRITERIA INADEQUATE	CRITERIA NON-EXISTENT
M1			
Unique Components	54%	36%	9%
Non-unique Components	80%	20%	0%
FIST-V	83%	7%	10%
MLRS			
Self-Propelled Launcher Loader	78%	22%	0%
Heavy-Expanded Mobility Tactical Truck	82%	18%	0%

traced back more than two decades and can be identified in each of the services; HARDMAN was the most recent Army predecessor. Each successive effort has attempted to increase the breadth and sophistication of awareness of the need to integrate human factors into systems design and development. MANPRINT is the latest of these efforts and it appears to be the most insistent. Perhaps as demands for compliance multiply and as implementation becomes more concrete and customary, MANPRINT efforts will begin to improve the systems that are fielded and the operational tests that are conducted to evaluate these systems. Nonetheless, embedding human factors awareness into all phases, and especially into the early phases, of weapon system development will continue to pose challenges to system designers and human factors specialists alike.

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